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Protecting the Nation's Groundwater From Contamination

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Foreword

Contamination of groundwater is the focus of public attention nationwide—it is being detected with increasing frequency, it has been detected in every State and often near heavily populated areas, and it is linked to adverse health, economic, environmental, and social impacts. At the same time, groundwater is being increasingly relied on for many types of uses and currently supplies the Nation with one-half of its drinking water. The sense of public urgency is reflected in the hearings and debates of the 98th Congress to reauthorize major environmental laws including the Resource Conservation and Recovery Act, the Safe Drinking Water Act, the Clean Water Act, and the Comprehensive Environmental Response, Compensation, and Liability Act ("Superfund").

The objective of the OTA study, as requested by the Senate Committee on Environment and Public Works, is to assess the current status of the Nation's knowledge about and experience in dealing with groundwater contamination problems. Overall, the study shows that much information is available about sources of contamination, impacts, and technologies to guide national policy. In particular, the analysis indicates that, despite the establishment and expansion of numerous Federal and State programs in recent years, these efforts have a narrow focus from a groundwater perspective and, consequently, are limited in their ability to protect groundwater quality.

The study itself focuses on *existing* contamination problems because of the absence of a coherent technical foundation for understanding—i.e., integrating, analyzing, and interpreting--information about the problems caused by groundwater contamination from a national policy perspective. At the same time, OTA recognized that the prevention of *future* contamination would also need to be explicitly considered in order to develop a policy framework for comprehensive resource protection; for example, as experience with hazardous wastes has shown, the cost to clean up contamination can be *enormously* greater than the cost to prevent contamination. Thus, the structure of the study evolved around the concept of *protecting* groundwater quality—comprised of activities to detect, correct, and prevent groundwater contamination—even though the details focus on the detection and correction of existing problems.

Many individual topics related to groundwater contamination, such as prevention alternatives, the effects of specific sources on groundwater contamination, and the effectiveness of specific laws and programs have been explored in greater detail in other OTA studies. Interested readers are referred to, among others, *Assessment of Technologies for Determining Cancer Risks From the Environment* (June 1981), *Use of Models for Water Resources Management, Planning, and Policy* (August 1982), *Technologies and Management Strategies for Hazardous Waste Control* (March 1983), *The Information Content of Premanufacture Notices—A Background Paper* (April 1983), *Water-Related Technologies for Sustainable Agriculture in U.S. Arid and Semiarid Lands* (October 1983), *Managing Commercial High-Level Radioactive Waste* (in press), *Cleanup of Uncontrolled Hazardous Waste Sites Under Superfund* (in progress), and *Hazardous Materials Transportation: Technology Issues* (in progress).

The viewpoints of the private sector, environmental groups, academia, the technical community, and public interest organizations were sought in conducting the study. In addition, over two dozen Federal agencies and offices were contacted for the analysis of Federal laws and programs, and each of the States responded to the OTA State survey. OTA thanks the numerous people—advisory panel members, reviewers, advisors, and consultants—who gave so generously of their time and expertise in support of the study. As with all OTA studies, the content of the report is the sole responsibility of OTA.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The views expressed in this OTA report, however, are the sole responsibility of the Office of Technology Assessment.

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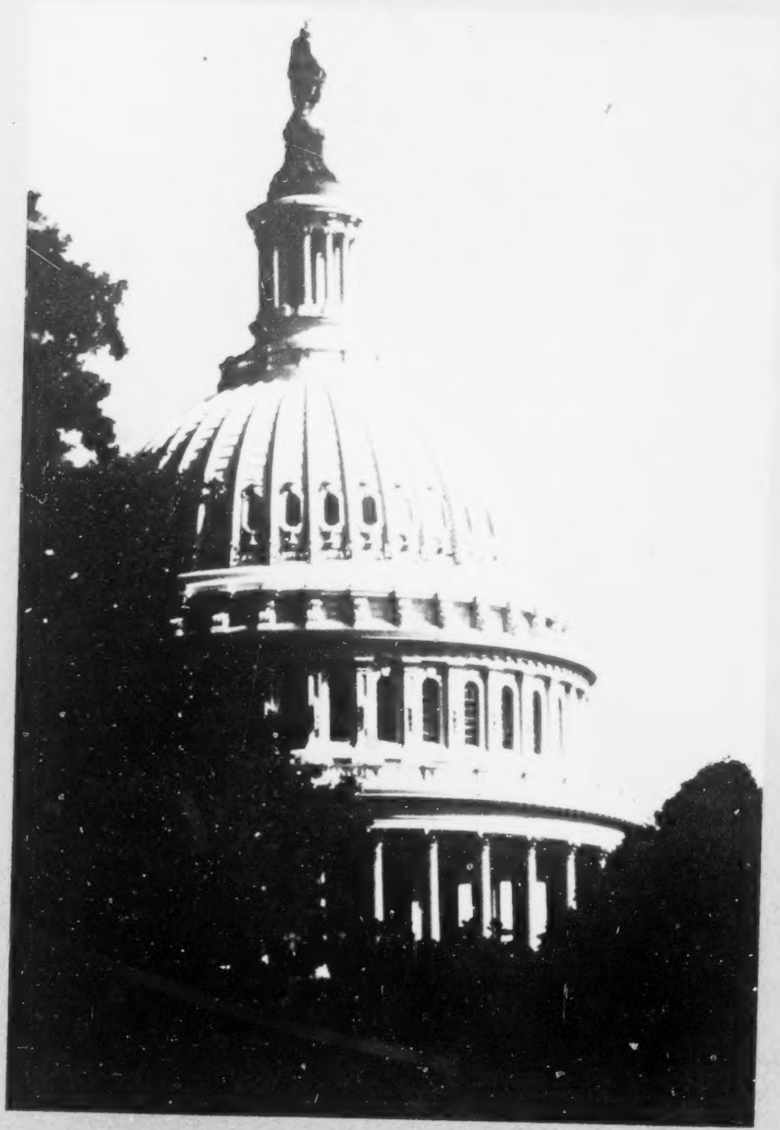
A. Groundwater Contamination and Its Impacts
B. Federal Institutional Framework To Protect Groundwater
C. State Institutional Framework To Protect Groundwater
D. Hydrogeologic Investigations of Groundwater Contamination
E. Federal Efforts To Detect Groundwater Contamination
F. Corrective Action: Technologies and Other Activities
G. Federal Efforts To Correct Groundwater Contamination
H. Federal Efforts To Prevent Groundwater Contamination

Report Summary and Findings



Chapter 1

Protecting the Nation's Groundwater From Contamination: Findings

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Chapter 1

Protecting the Nation's Groundwater From Contamination: Findings

CHAPTER OVERVIEW

Contamination of groundwater—by organic and inorganic chemicals, radionuclides, and/or microorganisms—has occurred in every State and is being detected with increasing frequency. For a long time, the land surface and subsurface were considered safe and convenient depositories for many of society's wastes and non-waste products. Only recently has the limited capacity of natural soil processes to change contaminants into harmless substances, before they reach groundwater, become widely recognized.

Detailed quantitative estimates of the nationwide extent and effects of groundwater contamination are not now, and probably never will be, available. The time, costs, and technical requirements to develop nationwide estimates would be prohibitive. In addition, information necessary for predicting future contamination problems—about future uses of groundwater, potential sources, and types of contaminants—cannot be known with certainty.

Contaminants found in groundwater—particularly organic chemicals—are associated with adverse health, social, environmental, and economic impacts. **Although only a small portion of the Nation's total groundwater resource is thought to be contaminated, the potential effects of this contamination are significant and warrant national attention.**

Public health concerns arise because some contaminants are individually linked to cancers, liver and kidney damage, and damage to the central nervous system. They also arise because information is not available about the health impacts of many other individual contaminants, or of mixtures of contaminants as typically found in groundwater. Uncertainties about human health impacts are likely to persist because impacts are difficult to study; for example, impacts may not be observable until long after exposure.

Social impacts are often related to anxiety and fear about exposure to contaminants. Exposure can occur unknowingly because even if groundwater is contaminated, it may be odorless, colorless, and tasteless. Exposure can also occur over many years and in many ways—by drinking, eating, bathing, and breathing.

Environmental impacts include the quality degradation of not only soil, but also air and surface water because of interrelationships among environmental media (e.g., groundwater can provide baseflow to streams). Vegetation, fish, and wildlife can be affected adversely.

The economic costs of detecting, correcting, and preventing groundwater contamination at even a single site are high; for example, corrective action can be tens of millions of dollars or more. Economic losses that occur from impaired groundwater quality include decreases in agricultural and industrial productivity, lowered property values, the costs for repair or replacement of damaged equipment and materials, and the costs of developing alternative water supplies.

Adverse impacts from groundwater contamination are likely to increase. Contaminated groundwater is often located near industrialized, heavily populated areas, which increases the likelihood of human exposure. Groundwater is also increasingly relied on as a source of water for many uses; withdrawals for all uses increased from about 35 billion gallons per day in 1950 to almost 90 billion gallons per day in 1980. Groundwater is now a source of drinking water for approximately one-half the Nation's population. It also fills about 40 percent of the Nation's irrigation requirements, about 80 percent of rural requirements both in the home and for livestock, and about 25 percent of self-supplied industrial purposes (other than hydroelectric power).

Current information about the Nation's groundwater contamination problems may not describe the actual situation as much as it reflects the way in which investigations are conducted—which contaminants have been looked for, where they have been looked for, and where they have been found. Because substances found as contaminants in groundwater are used throughout society, more widespread detection of contamination can be expected as efforts increase to monitor known problems, locate as yet undetected problems, and monitor potential problems. Known sources of contamination include not only the commonly recognized point sources associated with hazardous wastes (as defined by Federal statutes) but also non-point sources and sources associated with non-hazardous wastes and non-waste products.

Examples that reflect the diversity of known sources of contamination include: injection wells and septic tanks, which are designed to discharge potential contaminants into the ground; storage tanks and landfills, which are designed to store, treat, and/or dispose of potential contaminants; pipelines and transfer operations, which transport potential contaminants; agricultural practices, which include pesticide and fertilizer applications; production wells, which provide a conduit for potential contaminants to enter groundwater; and saltwater intrusion, which can be induced or worsened by human activities.

Groundwater contamination problems will continue, and probably increase, as long as there are sources, contaminants, and users not being addressed. **Despite the paucity of quantitative details, sufficient information is available about the nature of groundwater contamination to justify national action to protect groundwater quality—described in this study as involving choices among activities to *detect, correct,* and *prevent* contamination—in order to minimize associated adverse impacts. Policy options generally relate to the development and implementation of Federal and State protection programs and include a broadening of programs to those sources, contaminants, and users not now covered and the provision of adequate and sustained Federal support to the States.** Unfortunately, the costs and technical uncertainties associated with detection and correction activities effectively preclude the investigation and correction of all known and/or suspected contamination problems. Therefore, prevention is central to any long-term approach to groundwater quality protection. In general, selection among detection, correction, and prevention activities—given limited funds and technical capabilities—will depend on policy decisions regarding which and to what extent groundwater resources will be protected.

FEDERAL AND STATE APPROACH TO GROUNDWATER PROTECTION

Numerous Federal and State programs for protecting groundwater quality—for detecting, correcting, and preventing contamination--have been established and expanded in recent years. These efforts have made a significant contribution to the protection of groundwater. For example, sources of contamination have been identified, inventories of selected sources have been conducted, numerous incidents have been documented, and scientific advances have been made in understanding groundwater flow.

At the Federal level, at least 16 statutes authorize programs relevant to groundwater protection, and more than two dozen agencies and offices are involved in groundwater-related activities. All 50 States are concerned about contamination and have programs, at varying stages of development, to protect groundwater. As many as seven agencies with groundwater responsibilities have been identified in a single State.

Despite growing Federal and State efforts, programs are still limited in their ability to protect against contamination. For example, there is no explicit national legislative mandate to protect groundwater quality; and although the groundwater protection strategy of the U.S. Environmental Protection Agency acknowledges the need for comprehensive resource management, the details of the strategy do not fully provide for it. Most authorized programs are in their early stages, and some are at least 10 years from being fully in place. Groundwater quality-related programs among, and within, institutions are often not coordinated, nor are they coordinated with programs for groundwater quantity or surface water even though groundwater and surface water quality and quantity are interconnected.

From a groundwater protection viewpoint, existing Federal and State programs also generally have a narrow focus with respect to sources, contaminants, and users. Essentially, the programs are concerned with managing selected sources of contamination, selected contaminants, and the users of public drinking water supplies.

Narrow Focus on Sources.—Federal and State programs generally focus on managing only selected point sources of contamination, particularly point sources associated with hazardous wastes. **The programs vary in their approaches to protection of groundwater quality and generally do not take into account the potential of the sources to contribute to groundwater contamination. Further, the non-hazardous waste, non-waste, and non-point sources that are known to contaminate groundwater are usually not covered.**

Narrow Focus on Contaminants.—This study has documented the detection of over 200 substances—both natural and synthetic—in groundwater. Yet the Federal Government has established only 22 mandatory water quality standards, 18 of which are for specific chemicals. **These Federal standards, developed under the National Interim Primary Drinking Water Regulations of the Safe Drinking Water Act, are inadequate, as substantiated by State responses to the OTA State survey. As a result, many States have set their own standards for drinking water and groundwater quality; both the types of contaminants addressed and the stringency of standards vary from State to State.**

Narrow Focus on Users.—Federal and State programs are directed primarily at the protection of public drinking water supplies. Yet as much as 20 percent of the Nation's population may rely on private wells for drinking water. **The extent to which people relying on private wells are being exposed to groundwater contaminants is unknown, and data are generally not being collected to find out. Data are also unavailable about the impacts of groundwater contamination on non-drinking water uses.**

As a result of the narrow focus of Federal and State programs with respect to groundwater protection in terms of sources, contaminants, and

Photo credits: State of Florida Department of Environmental Regulation (left) and Office of Technology Assessment (right)

Sources of potential groundwater contamination are diverse and include the most commonly addressed point sources associated with hazardous wastes as well as sources associated with non-hazardous wastes (e.g., open dumps, which are usually point in nature and may also contain hazardous wastes) and non-wastes (e.g., product pipelines, which are non-point).

users, related activities to protect against contamination are also narrow in focus. Examples are described below.

Detection Programs

The focus of both inventorying and monitoring efforts is on selected point sources of contamination, primarily on sources of hazardous wastes. Federal inventories of specific sources are limited to surface water impoundments under the Safe Drinking Water Act and to hazardous waste sites and open dumps under the Resource Conservation and Recovery Act. State inventories are directed primarily at sources designed to store, treat, and/or dispose of wastes (e.g., landfills) and at sources designed to discharge potential contaminants into the subsurface (e.g., injection wells). In general, only recently has groundwater monitoring begun to include organic chemicals and trace metals. Routine monitoring is required only for public drinking water supplies, as opposed to private drinking water supplies and supplies for non-drinking water purposes.

Corrective Action Programs

Few corrective actions have been undertaken to date relative to the number of sites identified as requiring such action. For example, although federally funded corrective actions authorized by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as "Superfund") could potentially address a broad range of sources and contaminants, actions thus far have been restricted to primarily hazardous waste sites; in addition, such corrective actions have generally not involved the cleanup of contaminated groundwater. Overall, the provisions of Federal programs for corrective action vary. Two programs establish standards for cleanup (the Resource Conservation and Recovery Act and the Uranium Mill Tailings Radiation Control Act); other programs (e.g., CERCLA) establish cleanup standards on a case-by-case basis.

State corrective action programs are similarly at an early stage of development. The greatest number of State programs relate to spills and accidents and to leaks from storage; other activities tend to be associated with point sources that are designed either to retain (e.g., in landfills) or to discharge (e.g., via injection wells) potential contaminants into the subsurface. Many State corrective actions result from complaints rather than systematic efforts to identify contaminated sites.

Prevention Programs

A limited number of potential sources are addressed in Federal and State programs to prevent groundwater contamination. The programs focus primarily on sources associated with hazardous wastes and other toxic materials. Implementation and enforcement of most program requirements are still in their early stages. Differences among programs have little relationship to the potential for different sources to cause contamination. Current approaches to preventing contamination include provisions for the design, operation, siting, restricted use, and closing of sources. The approaches may be either mandatory or voluntary. Additional approaches to the prevention of groundwater contamination from specific sources include use of alternatives to the contaminating activity (e.g., to land disposal), process or product changes for reduction of waste hazard levels and volumes, and waste recycling and recovery.

A focus on sources is one approach to prevent contamination; other types of approaches have not been widely applied to groundwater. For example, few efforts have been made to control activities located in recharge areas (i.e., portions of a drainage basin that replenish an aquifer). Approaches that are not source-specific are most suitable when there is no single identifiable source or when high volumes of groundwater or large areas are involved (e.g., non- point sources or a clustering of point sources). The Federal Government does provide some support for the protection of *selected* recharge areas through the Sole Source Aquifer Program under the Safe Drinking Water Act; selected recharge areas are also being protected by some States and local governments through land use controls and land acquisition.

Another approach to prevent groundwater contamination is through restrictions on the manufacture or generation, distribution, and use of the contaminating substances themselves. This approach recognizes the fact that any one substance can be released into groundwater from many different sources. To illustrate, pesticides may be introduced from non-point sources such as land application, non-waste sources such as storage tanks, hazardous waste sources such as landfills, and non-hazardous waste sources such as residential disposal. Although both the Toxic Substances Control Act and the Federal Insecticide, Fungicide, and Rodenticide Act authorize regulation of potential groundwater contaminants, application of associated programs to groundwater has been limited.

TECHNICAL AND NON-TECHNICAL CONSTRAINTS

The effectiveness of Federal and State programs to protect groundwater from contamination has been limited not only by their narrow focus but also by technical and non-technical factors.

Underlying all groundwater protection activities is the hydrogeologic investigation which is used, for example, to detect existing problems, monitor the performance of corrective actions, and monitor the effectiveness of preventive activities. In general, the technologies for obtaining hydrogeologic information are available. Nevertheless, there will always be some degree of uncertainty about contamination because of inherent difficulties in dealing with a phenomenon that is inaccessible to direct observation. Many advances have been made to improve the reliability of results (i.e., to reduce uncertainty), but they often increase the costs and time required to conduct the investigation.

There are major constraints on hydrogeologic investigations in some situations. For example, the technology for conducting reliable investigations in certain geologic environments such as fractured rock, which occurs throughout the United States, is lacking. Investigations can also be very costly and time-consuming depending on site conditions and the level of detail required by the investigation objectives (e.g., investigations just to *define* a contamination problem could cost anywhere from $25,000 to $500,000 and take many months to complete). In addition, the reliability of a hydrogeologic investigation depends on highly skilled personnel because investigations must be tailored to the site-specific nature of any groundwater contamination problem. Adequately trained personnel are generally in short supply.

Many of the constraints associated with hydrogeologic investigations—costs, time, inadequate supply of trained personnel, and technical uncertainties—also apply to detection, correction, and prevention activities. The importance of the constraints to these activities varies, however, and additional constraints also become relevant.

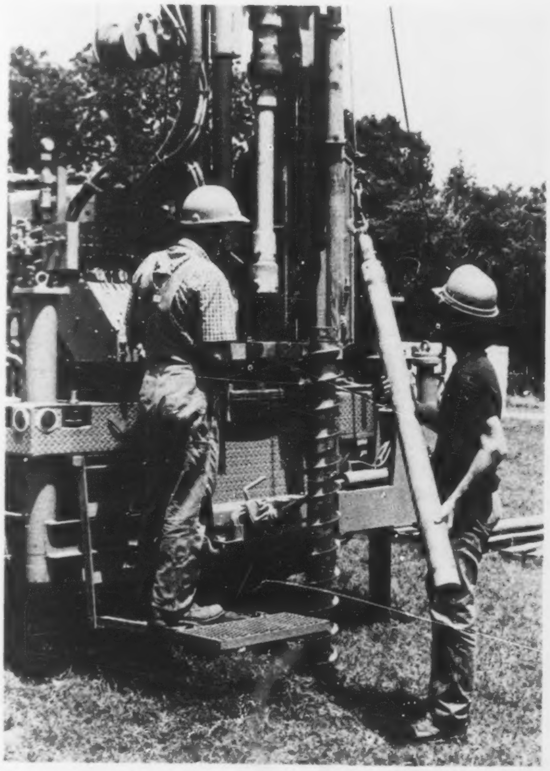

Photo credit: U.S. Environmental Protection Agency

In general, techniques for conducting hydrogeologic investigations are available for most environments. Here a drilling rig provides access to undisturbed, uncontaminated samples of a deep aquifer; a hollow-stem auger holds the drilling hole open while a sampling tube is lowered inside and pushed into undisturbed aquifer material.

Detection activities are primarily constrained by the high costs of monitoring. For example, the annual collection and analysis of groundwater quality samples from the 12-14 million private wells in the United States could cost $7 billion or more depending on the techniques used; and such a sampling program would still provide only a snapshot of data, at discrete places and for one point in time, that conveys little information about the sources of any existing contamination or the potential for further or future contamination. One institutional constraint on some States is their lack of authority to obtain data about particular sources of contamination.

Techniques for analyzing groundwater quality samples are biased in terms of which of the contaminants present they detect, and some contaminants cannot be readily measured at low but potentially harmful levels using routinely available methods. Water quality data can also be difficult to analyze and interpret, especially if trace levels or mixtures of contaminants are present or if contaminants have changed chemically and biologically into substances different than those expected.

Major constraints on alternatives for corrective action include: uncertainty about the effectiveness of various techniques to improve groundwater quality; the dependence of technology performance on the amounts of both money and time available; the high costs of taking corrective action of any sort; the need for suitably trained professionals to design and implement measures appropriate for site-specific conditions; and the lack of experience, especially with the large areas or large volumes of contaminated groundwater that are typical of non-point sources. The nature of the contaminants is another constraint; for example, treatment techniques can be costly depending on the contaminants present, and their performance is uncertain when there is a complex mixture of contaminants and/or concentrations change rapidly. Based on experience-to-date, correction alternatives—containment, withdrawal, treatment, in-situ rehabilitation, and management options—appear to be selected according to how rapidly they can be implemented, how rapidly they become effective, the extent to which the uncertainties inherent in their performance can be reduced, and whether there is clear authority to implement the selected strategy.

Photo credit: U.S. Environmental Protection Agency

Protective clothing is worn to prevent exposure to contaminants while undertaking corrective measures.

Institutional constraints on corrective actions relate to ease of access to the site, availability of alternatives for disposal of any contaminants withdrawn or excavated, and ability to implement some correction activities (e.g., withdrawal via pumping) given established water rights. Corrective action can also have environmental side-effects. For example, the management option of closing wells results in the continued presence of and potential for further migration of contaminants, and excavation may transfer contaminants to another site or other environmental media (e.g., surface water and air).

Major constraints on prevention efforts include the lack of funds to implement existing programs, uncertainty about the technical adequacy of available methods and ongoing efforts, and incomplete understanding about the relationship between land use and groundwater quality. Some techniques used to prevent contamination are the same as those used for correction (e.g., containment measures such as liners), so that the same uncertainties about performance are pertinent.

NATIONAL POLICY IMPLICATIONS

National policy options generally relate to the development and implementation of Federal and State groundwater quality protection programs.

The existing Federal statutory framework appears to have the *potential* to protect the Nation's groundwater from further contamination. **However, the realization of this potential will depend on broadening the coverage of authorized programs to those sources, contaminants, and users not presently included and on effectively implementing programs.** Many approaches for broadening and implementing programs are possible, such as mandatory requirements, voluntary procedures, and/or incentives and disincentives. Effective implementation will also require the coordination of activities among and within agencies (e.g., health departments, State geological surveys, and departments of environmental protection) for both groundwater and surface water quality and quantity. Ultimately, groundwater quality protection will also depend on political judgments about both the appropriate role of the Federal Government and the importance of all States making comparable progress in their abilities to detect, correct, and/or prevent groundwater contamination.

Fundamental to the development of any national policy related to the protection of groundwater from contamination is recognition of the site-specific nature of the problems. Efforts to detect, correct, and prevent contamination must be tailored to the full range of conditions found at any site, including sources, contaminants, and users. **National policy must be flexible in its ability to respond to and accommodate different groundwater quality problems characterized by varying site conditions.** For example, the choice of appropriate monitoring parameters, locations, and frequencies cannot be rigidly specified apart from site conditions; however, the factors that need to be considered in making this choice could be specified. **A major function of the Federal Government would be to provide adequate and sustained support to the States for detecting, correcting, and preventing groundwater contamination. The principal areas for Federal support to the States that would be the most helpful in achieving groundwater quality protection are funding, technical assistance, and research and development.**

The need for flexibility in national policy is underscored by the vast differences among State approaches to protecting groundwater. States vary in their perception about their contamination problems, priorities among sources and users, capabilities, stages of program development and implementation, and institutional arrangements. Land use considerations, essential for preventing contamination from non-point sources or from clusters of point sources, have traditionally been addressed at the State and local levels.

Current Federal laws and programs have generally helped the States with their groundwater contamination problems. However, based on responses to the OTA State survey, the level of Federal support to the States is not adequate; nor is it directed at all of the States' problems. In some cases, current Federal laws and programs have created problems: surface water quality problems have been reduced at the expense of groundwater quality because Federal programs fail to recognize the interrelationships among environmental media; Federal programs fail to accommodate variations in State conditions; and the lack of an explicit national legislative goal to protect groundwater quality has led to uncoordinated Federal programs and has handicapped the States in obtaining authority to address certain problems.

Funding

Currently no Federal program has earmarked funds specifically for the protection of groundwater quality. In addition, funding for programs that have supported groundwater-related activities has been reduced or eliminated (e.g., funding under Section 208 of the Clean Water Act, for State solid waste programs under Subtitle D of the Resource Conservation and Recovery Act, and for the Rural Abandoned Mine Program under the Surface Mining Control and Reclamation Act). As a result,

Photo credit: Charles O'Hear, U.S. Environmental Protection Agency

Many States lack adequate authority to deal with agriculturally related sources of groundwater contamination including pesticide and fertilizer applications and agricultural wastes.

groundwater and other water quality programs are competing for limited State grants (e.g., under Sections 106 and 205(j) of the Clean Water Act). Because of the high costs associated with groundwater protection, Federal funding assistance is desired by the States for both the development *and* implementation of State initiatives.

Technical Assistance

Technical assistance to the States can include training programs, the development of criteria and/or guidelines, and information exchange.

Qualified personnel are essential for protection activities because activities need to be tailored to site conditions. **The supply of qualified technical personnel appears to be limited and to be an important constraint on the Nation's ability to protect groundwater quality.** Federal support for training and education is required for a *rapid* increase in the Nation's technical capabilities. The States have been assisted by the Cooperative Program of the U.S. Geological Survey, and they would like to see it and other technical assistance programs continued. Establishment of professional certification programs or other criteria (e.g., by the Federal Government, the States, or professional societies) for ensuring that personnel possess minimum technical qualifications would also help to develop—and to provide a check in the hiring of—qualified technical manpower.

Although contamination problems require site-specific judgments, they nevertheless have common features that are amenable to the development of Federal criteria and/or guidelines. From a national perspective, the goal of these criteria and/or guidelines would be to ensure that *at least* a minimum set of considerations is being taken into account for protection of groundwater quality. Further, they would also be an efficient means of providing information required by all States in handling their groundwater contamination problems; for example, general guidelines could be developed for assisting the States in setting priorities for allocating scarce resources among alternative protection activities. In addition to criteria and guidelines, the Federal Government could provide direct assistance to States in specified situations.

Technical assistance could include:

- With respect to detection:
  - — Criteria and/or guidelines to assist the States in conducting reliable hydrogeologic investigations under different site conditions and in addressing, for example, monitoring of the flow system, sampling and analysis, and data interpretation.
  - — Criteria and/or guidelines for addressing contaminants for which there are no Federal standards, including for mixtures. Standards development for these contaminants is also needed (see *Research and Development,* below).
  - — Criteria and/or guidelines to assist the States in setting priorities among sources and in determining which sources they will monitor and inventory.
- With respect to correction:
  - — Criteria and/or guidelines to assist the States in selecting and implementing corrective action under various conditions.
  - — Criteria and/or guidelines for setting cleanup standards on a site-specific basis, incorporating such factors as the limitations and likely performance of technology and current and/or potential users.
- With respect to prevention:
  - — Criteria and/or guidelines for preventing contamination from all potential contaminating sources; for a given source, performance criteria and/or guidelines for addressing its siting, design and operation during its active life, and closure. Alternatives for reducing the wastes generated by a source, and for waste recycling, also need to be considered as part of preventing contamination from sources.
  - — Criteria and/or guidelines for considering prevention alternatives apart from those related to specific sources, e.g., for the protection of aquifer recharge areas and for establishing an institutional memory for the locations of sources, contaminants, and land uses.

Because of the complexities of groundwater contamination problems and because efforts to protect groundwater are generally in their early stages, there are several important opportunities for the Federal Government to facilitate information exchange among the States. Information exchange would not necessarily include the details of site-specific case studies; rather, programmatic information about State approaches to protection would assist the States in learning from the successes, and failures, of each other.

Photo credit: John Gilbert, EPA Environmental Response Team

Training of staff is required for dealing safely and effectively with site-specific groundwater contamination problems.

Research and Development

Some research and development activities can provide timely information that would support all of the States in their groundwater protection efforts. Key activities include:

- With respect to detection:
  - — Research on toxicology and the adverse health effects of contaminants that are being found in groundwater, with particular emphasis on the synergistic effects of mixtures of contaminants.
  - — Development of water quality standards for substances known to occur in ground-

  water that are not now covered; these standards could be applied in State drinking water and groundwater quality programs.
  - Research on assessment of the environmental and economic impacts of contamination.
  - Research on less costly techniques for hydrogeologic investigations in general and development of reliable techniques for conditions that cannot now be addressed adequately (e.g., fractured rock).
- With respect to correction:
  - Research on the behavior of individual contaminants in groundwater and, in particular, on the potential for the chemical and biological transformation of organic chemicals.
  - Research on chemical and biological reactions in fluids that would be necessary, for example, for the development of techniques for treating water with multiple contaminants.
- With respect to prevention:
  - Opportunities and mechanisms for preventing contamination, including ways of reducing the generation (e.g., by process or product changes) and disposal (e.g., through resource recovery and recycling) of potential contaminants.

Ultimately, the protection of groundwater from contamination will also depend on raising the consciousness of the public as has been done for littering and air and surface water pollution. All segments of society need to understand how their activities affect groundwater quality and, in turn, how they may be affected. Public confidence will grow only as the Nation makes timely efforts to detect, correct, and prevent groundwater contamination from all sources and contaminants, to protect all of the public's interests.

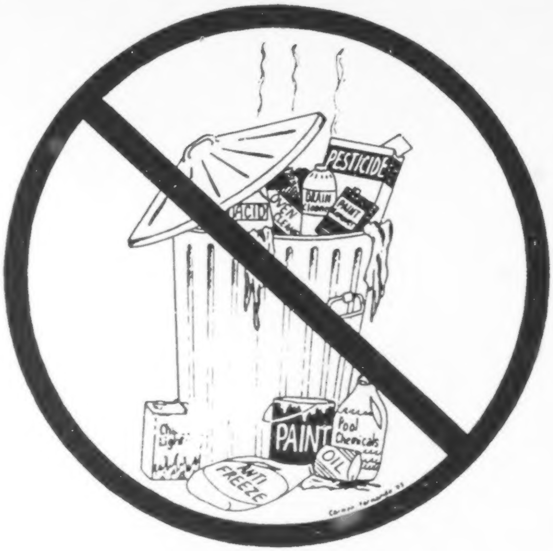

Illustration credit: Sacramento County, CA

Some communities have implemented household hazardous waste collection programs as part of their efforts to protect groundwater quality.

Background

Chapter 2

Groundwater Contamination and Its Impacts

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Chapter 2
Groundwater Contamination and Its Impacts

CHAPTER OVERVIEW

Groundwater is an increasingly important resource in the United States—it is relied on for about 50 percent of drinking water supplies; it is used to supply water for almost 80 percent of rural domestic and livestock needs, about 40 percent of irrigation needs, many commercial activities, and almost 25 percent of self-supplied industrial needs (other than thermoelectric power); it is used for stream flow maintenance and as a barrier to salt-water intrusion; and it is both an intentional and unintentional depository for society's waste and non-waste products (USGS, 1983a).

The degree of reliance on groundwater varies significantly around the Nation. For example, groundwater withdrawals for public water supplies vary from 11 percent in the Great Lakes region to 75 percent in the Rio Grande region, for rural uses from 12 percent in the Upper Colorado to 100 percent in New England, and for irrigation from 1 percent in the Upper Colorado to over 90 percent in the Upper Mississippi.

Contamination of the Nation's groundwater resource has recently become an issue of widespread public concern. This chapter analyzes current knowledge about the nationwide extent of contamination, the substances[1] known to occur in groundwater and their associated impacts, and known sources of contamination. Specific topics addressed are:

- the extent of groundwater contamination and difficulties in its assessment;
- substances known to occur in groundwater and their uses;
- health impacts of contamination;
- non-health impacts of contamination (e.g., economic and environmental impacts);
- concentration and frequency of compounds in groundwater;
- potential but as yet undetected substances in groundwater;
- types of sources and their associated substances;
- factors influencing a source's potential to contaminate groundwater (including estimates of numbers of sources and amounts of material flowing through or stored in sources); and
- the potential for sources to contaminate groundwater.

Major conclusions drawn from this information are summarized below.

The portion of the Nation's groundwater resources that is contaminated is believed by experts to be small. No matter how small, this portion is nevertheless significant because of its location near heavily populated areas and because of the many uses of and increasing dependence on groundwater. The site-to-site variability of contamination, combined with the expense and time required to investigate potential contamination problems, means that a detailed nationwide description of groundwater quality may never be attainable.

A variety of adverse impacts due to groundwater contamination is possible—including effects on public health, the environment, agricultural productivity (e.g., due to increased salinity in irrigation water), and on the output of industries requiring high-quality water. Public attention has focused primarily on the potential for health effects; because little information is available on other impacts, this chapter focuses on potential damage to human health.

Even if a comprehensive description of groundwater quality were available, the magnitude and exact nature of public health effects resulting from contamination could not be estimated with confidence. At best, evidence would involve the documentation of effects attributable to contamination, with predictions regarding the magnitude and types of future effects. This type of information is typically obtained from risk assessment analyses, wherein data on: 1) the adverse effects and 2) toxicity (i.e., dosage levels at which adverse effects are observed) of substances are linked with 3) exposure data to identify probabilities of adverse impacts on human health.

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[1] Substance is defined in this study as any organic or inorganic chemical, micro-organism, radionuclide, or other material (e.g., sediments). Whether or not a substance is a "contaminant" depends on its association with adverse impacts and on other site-specific factors (e.g., hydrogeology).

Data limitations preclude a risk assessment of the magnitude of public health risks from groundwater. Some of the data required for risk assessment analysis of groundwater contamination are available, primarily regarding known or possible hazards and known toxicities, but much of this information is not precise enough. Almost no data are available on human exposure to the substances of concern. These types of data are not likely to be obtainable in sufficient detail in most cases because of the inherent limitations of epidemiological investigations. For example, data would be needed—and, again, are probably unattainable—on the amount of exposure to substances from only groundwater (e.g., as opposed to exposure to the same substances from other media such as air and surface water), on the number of people exposed to various concentrations, and on interactions among substances when more than one substance is present.

Although the magnitude of the impacts of groundwater contamination cannot be estimated with confidence, the *nature* of many impacts is known. There is also a substantial body of indirect evidence indicating the large *potential* for groundwater contamination and subsequent health effects. Over 200 substances have already been detected in groundwater—substances that are used throughout society in a multiplicity of commercial, industrial, and household activities. For some, but not all, of these known substances, information is available about their adverse effects on laboratory animals and humans, toxicity levels, and the range of concentrations found in groundwater. Many of the substances present in groundwater can cause liver and kidney damage, damage to the central nervous system, cancers, and eye and skin irritation.

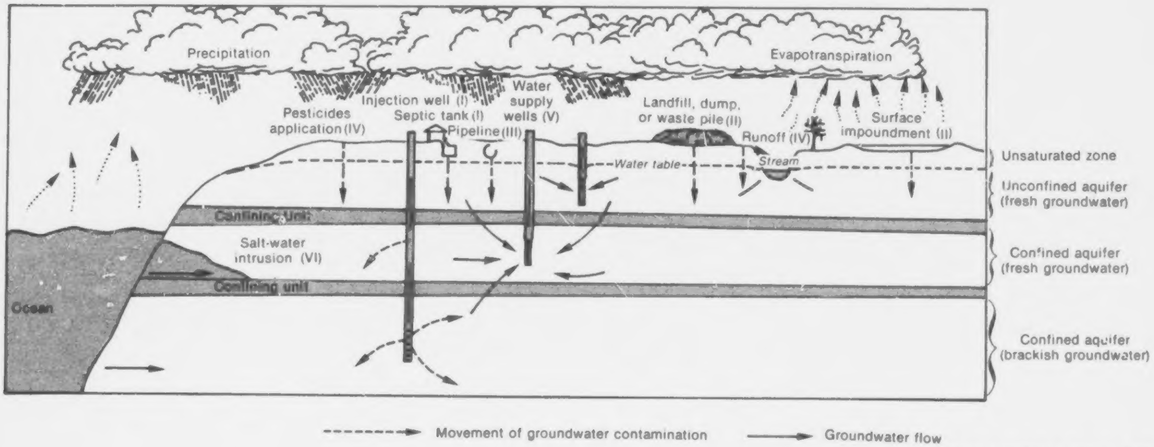
The pathways by which substances eventually enter groundwater are diverse and extremely complex—i.e., they can enter during production, handling, storage, processing, disposal, transport, and use. One focal point along these pathways, which Congress has started to address in recent legislation, is the *sources* from which contaminants enter groundwater. Sources of contamination are convenient for assessing possible detection, correction, and prevention actions. At least 33 major sources are known. There is a vast diversity among sources in terms of their associated substances, release characteristics, amounts of materials, geographic location, and role in society.

So far, most attention given to sources has concerned waste discharges (particularly hazardous wastes) from point sources. As shown by OTA's analysis, many potential sources of contamination also are associated with both non-hazardous wastes and non-waste products; and contaminants can enter groundwater from both point and non-point sources. Important advances have been made in the information base concerning sources since the U.S. Environmental Protection Agency's 1977 Report to Congress on waste disposal practices (EPA, 1977).

EXTENT AND NATURE OF GROUNDWATER CONTAMINATION

Assessing the Nationwide Extent of Groundwater Contamination

Although contamination of surface water has long been of concern to the public and to Congress—as demonstrated by passage of the Federal Water Pollution Control Act (the Clean Water Act) and the Safe Drinking Water Act—groundwater contamination has historically received little attention at the national level. One major reason was the common belief that groundwater was pristine, i.e., that potential contaminants percolating through the subsurface would adhere to the soil or be degraded by natural processes and, therefore, would


Precipitation
Evapotranspiration
Injection well (I)
Water supply wells (V)
Pesticides application (IV)
Septic tank (I)
Pipeline (III)
Landfill, dump, or waste pile (II)
Runoff (IV)
Surface impoundment (II)
Water table
Stream
Unsaturated zone
Unconfined aquifer (fresh groundwater)
Confining unit
Salt-water intrusion (VI)
Confined aquifer (fresh groundwater)
Confining unit
Ocean
Confined aquifer (brackish groundwater)
Movement of groundwater contamination
Groundwater flow

Credit: Geraghty & Miller, 1983

Pathways of groundwater contamination vary depending on the source. Examples of sources are shown here for each of OTA's six source categories (I-VI) (see the section on Types of Sources and Associated Substances, below).

not enter or greatly affect groundwater quality. Thus the subsurface, and groundwater, had been regarded as a safe and convenient depository for the wastes and non-waste byproducts generated by society.

But there is a growing consensus that the quality of groundwater is in decline. Incidents of contamination are being reported with increasing frequency and have now occurred in every State. Although the activities and practices that cause contamination are varied and were often begun many years ago, groundwater contamination recently has come to the attention of the public, primarily in the context of threats to human health. Most of the attention has focused on sources associated with hazardous wastes (e.g., landfills, surface impoundments, and waste piles) because of the severity of their impacts on surrounding populations and environments—groundwater has been seriously contaminated by toxic chemicals associated with these sources in at least 34 States (CEQ, 1981). However, non-hazardous wastes and non-wastes also contribute to the contamination of groundwater.

A small amount of the Nation's groundwater is generally believed to be contaminated (estimates range from about 1-2 percent). Although this portion may seem very small, it is significant because contamination is often near heavily populated areas and groundwater is being increasingly relied on for a variety of uses.

The extent of groundwater contamination is also likely to be greater than 1-2 percent. Descriptions of groundwater quality problems often include anecdotal or non-comparable data, making them difficult to interpret and analyze. In addition, much of the current information on the extent and magnitude of contamination reflects only the nature of investigations—where and which substances have been looked for and where they have been found. For example, groundwater that is not used for public drinking water supplies is not always tested, and more information is generally available about hazardous waste sources than about non-point sources and sources with non-hazardous wastes and non-waste products. Further, substances known to contaminate groundwater are used throughout society; thus, more widespread detection of contamination can be expected as efforts increase to monitor known, as yet undetected, and potential problems. Little is known about how much contamination is reversible and how rapidly new sites and sources of contamination are being created.

A complete description of contamination would require detailed information about groundwater

Photo credit: State of Florida Department of Environmental Regulation

Thirty-four of the 100 largest cities in the United States rely completely or partially on groundwater.

quality on a site-by-site basis throughout the Nation and about associated site-specific hydrogeologic conditions (e.g., the vulnerability of groundwater to the entrance of substances). A difficulty in assessing the extent of groundwater contamination is that not all substances entering groundwater may have adverse impacts. **Whether the presence of substances in groundwater results in a contamination problem depends on site-specific hydrogeology, the potential for adverse impacts** (health, economic, environmental, and social), **current and future groundwater use patterns, the exposure of humans to the substances, the availability of alternative water supplies, and the feasibility of corrective measures including management alternatives.**

The lack of data about groundwater quality stems from the technical complexity of groundwater. Groundwater and associated problems often cannot be directly observed and are not easily measured, and the behavior of substances in groundwater is not well understood—the movement of substances varies temporally and spatially in different hydrogeologic environments, and chemical and biological processes can alter the nature and subsequent behavior of substances. For these reasons, groundwater contamination problems are highly site-specific. Given this complexity and the costs and time that would be needed to gather data, **a complete description of groundwater quality may never, for all practical purposes, be attainable.**

Substances Known to Occur in Groundwater

As part of the OTA study, information was gathered that documents the presence of over 200 substances known to occur in the Nation's groundwater. Specific substances detected in groundwater thus far, and examples of major uses of these substances, are shown in table 1. These substances include about 175 organic chemicals, over 50 inorganic chemicals (metals, non-metals, and inorganic acids), biological organisms, and radionuclides.

The presence of substances in groundwater and an understanding of how, why, and where they are present are directly related to their use and/or disposition. As shown in table 1, many substances found in groundwater are widely used by industry, agriculture, commerce, and households. Potential contaminants can thus enter groundwater at numerous points as materials flow through society. Although most points-of-entry are associated with particular sources, the sources themselves are not the only places for controlling the entry of substances to groundwater (preventive strategies are discussed in chs. 11 and 12). However, focusing on sources is convenient to assess how substances enter groundwater. The relationship between substances and specific sources is discussed below in *Types of Sources and Associated Substances*.

Detection of substances in groundwater is biased not only by sampling and analytical limitations (see ch. 5) but also by the circumstances that prompted detection and reporting. There appear to be two major circumstances under which substances are being detected in groundwater: 1) as the result of planned activities (e.g., regulatory compliance, analysis and data management activities, routine monitoring, research, and liability protection); and 2) in response to apparent impacts (e.g., citizen complaints stemming from the observable or feared presence of substances, accidents, and aerial photography) (University of Oklahoma, 1983). The two most frequently cited reasons for detection of substances are regulatory compliance as a planned activity and response to public complaints. Reliance on public observation probably will not lead to the detection of many substances—most substances of concern are odorless, colorless, and otherwise unobservable without use of special analytical equipment.

HEALTH IMPACTS

General Issues

Many naturally occurring and synthetic substances can cause biological injury, disease, or death under certain conditions of exposure. Whether injury or illness occurs depends on many factors, including properties of the substance, dosage of and exposure to the substance, and characteristics of the individuals exposed. Many of the diseases and effects associated with groundwater contaminants are discussed below; however, data are insufficient for determining the relative importance of these contaminants in causing various effects.

Relationships between health impacts and different groups of substances—organic and inorganic chemicals (non-radioactive), micro-organisms, and radionuclides—are not understood with the same degree of knowledge and certainty. For example, there is a long history of public health efforts to understand and address micro-organisms, albeit primarily in surface water, and many sources of data are available. Radionuclides have been studied extensively since the 1940s, and much is now known about their health impacts, although not often at low concentrations. In contrast, health effects resulting from exposure to many chemicals are not well understood, in large part because of the relatively recent occurrence of and exposure to certain chemicals in the environment. Health effects of chemicals are of the greatest concern because chemicals are pervasive and persist in the environment.

Assessing risks from substances in groundwater requires information about adverse effects, toxicity, and exposure (extensive details on risk assessment are available in NAS, 1983, and Environ Corp., 1983; a brief summary is presented in app. A.1.); and available data are often insufficient to conduct such an assessment. Thus human health impair-

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]

Contaminant	Concentration[b] (parts per billion)	Standard[c]	Examples of uses[d]	Carcino-genic potency[e,f]	Noncarcino-genic toxicity[e,g]
Aromatic hydrocarbons					
Acetanilide	—		Intermediate manufacturing, pharmaceuticals, dyestuffs		
Alkyl benzene sulfonates	—	•	Detergents		
Aniline	—		Dyestuffs, intermediate, photographic chemicals, pharmaceuticals, herbicides, fungicides, petroleum refining, explosives		
Anthracene	18[h]		Dyestuffs, intermediate, semiconductor research		
Benzene	0.6-20,230	•	Detergents, intermediate, solvents, antiknock gasoline	Low	
Benzidine	—		Dyestuffs, reagent, stiffening agent in rubber compounding	High	
Benzyl alcohol	—		Solvent, perfumes and flavors, photographic developer inks, dyestuffs, intermediate		
Butoxymethylbenzene	—		NA[i]		
Chrysene	10		Organic synthesis		
Creosote mixture	—		Wood preservatives, disinfectants		
Dibenz[a.h.]anthracene	—		NA[i]		
Di-butyl-p-benzoquinone	—		NA[i]		
Dihydrotrimethylquinoline	—		Rubber antioxidant		
4,4-Dinitrosodiphenylamine	—		NA[i]		
Ethylbenzene	0.9-4,000	•	Intermediate, solvent		
Fluoranthene	31	•	NA[i]		Low
Fluorene	—		Resinous products, dyestuffs, insecticides		
Fluorescein	—		Dyestuffs		
Isopropyl benzene	290		Solvent, chemical manufacturing		
4,4′-Methylene-bis-2-chloroaniline (MOCA)	—		Curing agent for polyurethanes and epoxy resins	Low	
Methylthiobenzothiazole	—		—		
Naphthalene	6.7-82	•	Solvent, lubricant, explosives, preservatives, intermediate, fungicide, moth repellant		Low
o-Nitroaniline	—		Dyestuffs, intermediate, interior paint pigments, chemical manufacturing		
Nitrobenzene	—		Solvent, polishes, chemical manufacturing		
4-Nitrophenol	—		Chemical manufacturing		Moderate
n-Nitrosodiphenylamine	—		Pesticides, retarder of vulcanization of rubber		
Phenanthrene	18-471[h]		Dyestuffs, explosives, synthesis of drugs, biochemical research		
n-Propylbenzene	—		Dyestuffs, solvent		
Pyrene	48		Biochemical research		
Styrene (vinyl benzene)	—	•	Plastics, resins, protective coatings, intermediate		Low
Toluene	0.1-6,400	•	Adhesive solvent in plastics, solvent, aviation and high octane blending stock, dilutent and thinner, chemicals, explosives, detergents		Low
1,2,4-Trimethylbenzene	—		Manufacture of dyestuffs, pharmaceuticals, chemical manufacturing		
Xylenes (m,o,p)	0.07-300	•	Aviation gasoline, protective coatings, solvent, synthesis of organic chemicals		Low
Oxygenated hydrocarbons					
Acetic acid	—		Food additives, plastics, dyestuffs, pharamaceuticals photographic chemicals, insecticides		Low

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b] (parts per billion)	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Oxygenated hydrocarbons (cont'd)					
Acetone	10-3,000		Dyestuffs, solvent, chemical manufacturing, cleaning and drying of precision equipment		Low
Benzophenone	—		Organic synthesis, odor fixative, flavoring, pharmaceuticals		
Butyl acetate	—		Solvent		Low
n-Butyl-benzylphthalate	10-38		Plastics, intermediate		
Di-n-butyl phthalate	470	•	Plasticizer, solvent, adhesives, insecticides, safety glass, inks, paper coatings		Low
Diethyl ether	—		Chemical manufacturing, solvent, analytical chemistry, anesthetic, perfumes		
Diethyl phthalate	—	•	Plastics, explosives, solvent, insecticides, perfumes		
Diisopropyl ether	20-34		Solvent, rubber cements, paint and varnish removers		
2,4-Dimethyl-3-hexanol	—		Intermediate, solvent, lubricant		
2,4-Dimethyl phenol	—		Pharmaceuticals, plastics, disinfectants, solvent, dyestuffs, insecticides, fungicides, additives to lubricants and gasolines		
Di-n-octyl phthalate	23		Plasticizer for polyvinyl chloride and other vinyls		
1,4-Dioxane	2,100	•	Solvent, lacquers, paints, varnishes, cleaning and detergent preparations, fumigants, paint and varnish removers, wetting agent, cosmetics		
Ethyl acrylate	—		Polymers, acrylic paints, intermediate		
Formic acid	—		Dyeing and finishing, chemicals, manufacture of fumigants, insecticides, solvents, plastics, refrigerants		
Methanol (methyl alcohol)	—		Chemical manufacturing, solvents, automotive antifreeze, fuels		High
Methylcyclohexanone	—		Solvent, lacquers		
Methyl ethyl ketone	—		Solvent, paint removers, cements and adhesives, cleaning fluids, printing, acrylic coatings		
Methylphenyl acetamide	—		Na[i]		
Phenols (e.g., p-Tert-butylphenol)	10-234,000	•	Resins, solvent, pharmaceuticals, reagent, dyestuffs and indicators, germicidal paints		
Phthalic acid	—		Dyestuffs, medicine, perfumes, reagent		
2-Propanol	—		Chemical manufacturing, solvent, deicing agent, pharmaceuticals, perfumes, lacquers, dehydrating agent, preservatives		
2-Propyl-1-heptanol	—		Solvent		
Tetrahydrofuran	—		Solvent		
Varsol	—		Paint and varnish thinner		
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F)					
Acetyl chloride	—		Dyestuffs, pharmaceuticals, organic preparations		
Alachlor (Lasso)	190-1,700	•	Herbicides		Moderate
Aldicarb (sulfoxide and sulfone; Temik)	36-405	•	Insecticide, nematocide		High
Aldrin	—	•	Insecticides	High	
Atrazine	—	•	Herbicides, plant growth regulator, weed control agent		Moderate
Benzoyl chloride	—		Medicine, intermediate		
Bromacil	72-110	•	Herbicides		Moderate
Bromobenzene	1.9-5.8		Solvent, motor oils, organic synthesis		Moderate

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcino-genic potency[e,f]	Noncarcino-genic toxicity[e,g]
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
Bromochloromethane	—		Fire extinguishers, organic synthesis		Low
Bromodichloromethane	1.4-110	·	Solvent, fire extinguisher fluid, mineral and salt separations		
Bromoform	2.4-110		Solvent, intermediate		Moderate
Carbofuran	4-160	·	Insecticide, nematocide		Moderate
Carbon tetrachloride	0.3-18,700	·	Degreasers, refrigerants and propellants, fumigants, chemical manufacturing	Moderate	
Chlordane	—	•	Insecticides, oil emulsions		
Chlorobenzene	2.7-41	•	Solvent, pesticides, chemical manufacturing		Moderate
Chloroform	1.4-1,890	·	Plastics, fumigants, insecticides, refrigerants and propellants		
Chlorohexane	—		NA[i]		
Chloromethane (methyl chloride)	44		Refrigerants, medicine, propellants, herbicide, organic synthesis		Low
Chloromethyl sulfide	—		NA[i]		
2-Chloronaphthalene	83		Oil: plasticizer, solvent for dyestuffs, varnish gums and resins, waxes wax: moisture-, flame-, acid-, and insect-proofing of fibrous materials; moisture- and flame-proofing of electrical cable; solvent (see oil)		
Chlorpyrifos	—		NA[i]		
Chlorthal-methyl (DCPA, or Dacthal)	—		Herbicide		
o-Chlorotoluene	2.4		Solvent, intermediate		
p-Chlorotoluene	—		Solvent, intermediate		
Dibromochloromethane	2.1-55		Organic synthesis		
Dibromochloropropane (DBCP)	1-137	·	Fumigant, nematocide		
Dibromodichloroethylene	—		NA[i]		
Dibromoethane (ethylene dibromide, EDB)	35-300	·	Fumigant, nematocide, solvent, waterproofing preparations, organic synthesis		
Dibromomethane	44.9		Organic synthesis, solvent		
Dichlofenthion (DCFT)	—		Pesticides		
o-Dichlorobenzene	2.7	•	Solvent, fumigants, dyestuffs, insecticides, degreasers, polishes, industrial odor control		Moderate
p-Dichlorobenzene	0.6-0.7	·	Insecticides, moth repellant, germicide, space odorant, intermediate, fumigants		Moderate
Dichlorobenzidine	—		Intermediate, curing agent for resins	Moderate	
Dichlorocyclooctadiene	—		Pesticides		
Dichlorodiphenyldichloroethane (DDD, TDE)	—		Insecticides		Low
Dichlorodiphenyldichloroethylene (DDE)	0.01-0.8		Degradation product of DDT, found as an impurity in DDT residues		
Dichlorodiphenyltrichloroethane (DDT)	0.05-0.22	•	Pesticides	High	
1,1-Dichloroethane	0.5-11,330		Solvent, fumigants, medicine		Low

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
1,2-Dichloroethane	250–847	•	Solvent, degreasers, soaps and scouring compounds, organic synthesis, additive in antiknock gasoline, paint and finish removers	Low	
1,1-Dichloroethylene (vinylidiene chloride)	1.2–4,000	•	Saran (used in screens, upholstery, fabrics, carpets, etc.), adhesives, synthetic fibers	Moderate	
1,2-Dichloroethylene (cis and trans)	0.2–323	•	Solvent, perfumes, lacquers, thermoplastics, dye extraction, organic synthesis, medicine		
Dichloroethyl ether	1,100		Solvent, organic synthesis, paints, varnishes, lacquers, finish removers, drycleaning, fumigants		
Dichloroiodomethane	2.8–4.1		NA[i]		
Dichloroisopropylether (= bis-2-chloroisopropylether)	—		Solvent, paint and varnish removers, cleaning solutions		
Dichloromethane (methylene chloride)	4–8,400	•	Solvent, plastics, paint removers, propellants, blowing agent in foams		
Dichloropentadiene	0.36		NA[i]		
2,4-Dichlorophenol	—	•	Organic synthesis		
2,4-Dichlorophenoxyacetic acid (2,4-D)	1–85,000	•	Herbicides		Moderate
1,2-Dichloropropane	46–60	•	Solvent, intermediate, scouring compounds, fumigant, nematocide, additive for antiknock fluids		
Dieldrin	—	•	Insecticides	High	
Diiodomethane	2.0		Organic synthesis		
Diisopropylmethyl phosphonate (DIMP)	—	•	NA[i]		
Dimethyl disulfide	—		NA[i]		
Dimethylformamide	—		Solvent, organic synthesis		
2,4-Dinotrophenol (Dinoseb, DNBP)	124–400		Herbicides		Moderate
Dioxins (e.g., TCDD)	—	•	Impurity in the herbicide 2,4,5-T	High	
Dodecyl mercaptan (lauryl mercaptan)	—		Manufacture of synthetic rubber and plastics, pharmaceuticals, insecticides, fungicides		
Endosulfan	0.8	•	Insecticides		High
Endrin	—	•	Insecticides		High
Ethyl chloride	—		Chemical manufacturing, anesthetic, solvent, refrigerants, insecticides		
Bis-2-ethylhexylphthalate	12–170		Plastics	Low	
Di-2-ethylhexylphthalate	—	•	Plasticizers		
Fluorobenzene	67		Insecticide and larvicide intermediate		
Fluoroform	3.5		Refrigerants, intermediate, blowing agent for foams		
Heptachlor	—	•	Insecticides	Moderate	
Heptachlorepoxide	—	•	Degradation product of heptachlor, also acts as an insecticide		
Hexachlorobicycloheptadiene	2.2		NA[i]		
Hexachlorobutadiene	2.53		Solvent, transformer and hydraulic fluid, heat-transfer liquid		

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
α-Hexachlorocyclohexane (= Benzenehexachloride, or α-BHC)	6	•	Insecticides		
β-Hexachlorocyclohexane (β-BHC)	3.8	•	Insecticides		
γ-Hexachlorocyclohexane (γ-BHC, or Lindane)	0.5-43	•	Insecticides		Moderate
Hexachlorocyclopentadiene	—		Intermediate for resins, dyestuffs, pesticides, fungicides, pharmaceuticals		
Hexachloroethane	4.6		Solvent, pyrotechnics and smoke devices, explosives, organic synthesis	Low	
Hexachloronorbornadiene	—		NA[i]		
Kepone	—	•	Pesticides		High
Malathion	—	•	Insecticides		
Methoxychlor	—	•	Insecticides		Moderate
Methyl bromide	7.4		Fumigants, pesticides, organic synthesis		
Methyl parathion	4.6	•	Insecticides		
Parathion	—	•	Insecticides		High
Pentachlorophenol (PCP)	—	•	Insecticides, fungicides, bactericides, algicides, herbicides, wood preservative		Moderate
Phorate (Disulfoton)	—	•	Insecticides		
Polybrominated biphenyls (PBBs)	—		Flame retardant for plastics, paper, and textiles		Low
Polychlorinated biphenyls (PCBs)	8-40	•	Heat-exchange and insulating fluids in closed systems	Moderate	
Prometon	—		Herbicides		
RDX (Cyclonite)	3,400	•	Explosives		
Simazine	—	•	Herbicides	Moderate	
Tetrachlorobenzene	5,000	•	NA[i]		
Tetrachloroethanes (1,1,1,2 & 1,1,2,2)	4	•	Degreasers, paint removers, varnishes, lacquers, photographic film, organic synthesis, solvent, insecticides, fumigants, weed killer	Moderate	
Tetrachloroethylene (or perchloroethylene, PCE)	717-2,405	•	Degreasers, drycleaning, solvent, drying agent, chemical manufacturing, heat-transfer medium, vermifuge	Low	
Toxaphene	1-570	•	Insecticides	Moderate	
Triazine	2		Herbicides		
1,2,4-Trichlorobenzene	37		Solvent, dyestuffs, insecticides, lubricants, heat-transfer medium (e.g., coolant)		
Trichloroethanes (1,1,1 and 1,1,2)	0.2-26,000	•	Pesticides, degreasers, solvent	Low	
1,1,2-Trichloroethylene (TCE)	210-37,000	•	Degreasers, paints, drycleaning, dyestuffs, textiles, solvent, refrigerant and heat exchange liquid, fumigant, intermediate, aerospace operations	Low	
Trichlorofluoromethane (Freon 11)	26		Solvent, refrigerants, fire extinguishers, intermediate		Moderate
2,4,6-Trichlorophenol	—		Fungicides, herbicides, defoliant		Low
2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)	—	•	Herbicides, defoliant		Moderate

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Hydrocarbons with specific elements (e.g., with N,P,S,Cl,Br,I,F) (cont'd)	(parts per billion)				
2,4,5-Trichlorophenoxypropionic acid (2,4,5-TP or Silvex)	—	•	Herbicides and plant growth regulator		High
Trichlorotrifluoroethane	35-135		Drycleaning, fire extinguishers, refrigerants, intermediate, drying agent		
Trinitrotoluene (TNT	620-12,600	•	Explosives, intermediate in dyestuffs and photographic chemicals		
Tris-(2,3-dibromopropyl) phosphate	—		Flame retardant		
Vinyl chloride	50-740	•	Organic synthesis, polyvinyl chloride and copolymers, adhesives	Low	
Other hydrocarbons					
Alkyl sulfonates	—		Detergents		
Cyclohexane	540		Organic synthesis, solvent, oil extraction		
1,3,5,7-Cyclooctatetraene	—		Organic research		
Dicyclopentadiene (DCPD)	—		Intermediate for insecticides, paints and varnishes, flame retardants		
2,3-Dimethylhexane	—		NA[i]		
Fuel oil	—		Fuel, heating		
Gasoline	2,000-9,000	•	Fuel		
Jet fuels	—		Fuel		
Kerosene	243,000		Fuel, heating, solvent, insecticides		
Lignin	7,500[i]		Newsprint, ceramic binder, dyestuffs, drilling fuel additive, plastics		
Methylene blue activated substances (MBAs)	11	•	Dyestuffs, analytical chemistry		
Propane	—		Fuel, solvent, refrigerants, propellants, organic synthesis		
Tannin	7,500[i]		Chemical manufacturing, tanning, textiles, electroplating, inks, pharmaceuticals, photography, paper		
4,6,8-Trimethyl-1-nonene	—		NA[i]		
Undecane	—		Petroleum research, organic synthesis		
Metals and cations	(parts per million)				
Aluminum	0.1-1,200	•	Alloys, foundry, paints, protective coatings, electrical industry, packaging, building and construction, machinery and equipment		High
Antimony	—		Hardening alloys, solders, sheet and pipe, pyrotechnics		Moderate
Arsenic	0.01-2,100	•	Alloys, dyestuffs, medicine, solders, electronic devices, insecticides, rodenticides, herbicide, preservative	High	
Barium	2.8-3.8	•	Alloys, lubricant		High
Beryllium	less than 0.01	•	Structural material in space technology, inertial guidance systems, additive to rocket fuels, moderator and reflector of neutrons in nuclear reactors	Moderate	
Cadmium	0.01-180	•	Alloys, coatings, batteries, electrical equipment, fire protection systems, paints, fungicides, photography	High	
Calcium	0.5-225		Alloys, fertilizers, reducing agent		

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Metals and cations (cont'd)	(parts per million)				
Chromium	0.06-2,740	•	Alloys, protective coatings, paints, nuclear and high-temperature research	High	
Cobalt	0.01-0.18	•	Alloys, ceramics, drugs, paints, glass, printing, catalyst, electroplating, lamp filaments		High
Copper	0.01-2.8	•	Alloys, paints, electrical wiring, machinery, construction materials, electroplating, piping, insecticides		Moderate
Iron	0.04-6,200	•	Alloys, machinery, magnets		
Lead	0.01-5.6	•	Alloys, batteries, gasoline additive, sheet and pipe, paints, radiation shielding		High
Lithium	—	•	Alloys, pharmaceuticals, coolant, batteries, solders, propellants		Low
Magnesium	0.2-70		Alloys, batteries, pyrotechnics, precision instruments, optical mirrors		
Manganese	0.1-110	•	Alloys, purifying agent		High
Mercury	0.003-0.01	•	Alloys, electrical apparatus, instruments, fungicides, bactericides, mildew-proofing, paper, pharmaceuticals		High
Molybdenum	0.4-40	•	Alloys, pigments, lubricant		
Nickel	0.05-0.5	•	Alloys, ceramics, batteries, electroplating, catalyst	Moderate	High
Palladium	—		Alloys, catalyst, jewelry, protective coatings, electrical equipment		Low
Potassium	0.5-2.4		Alloys, catalyst		
Selenium	0.6-20	•	Alloys, electronics, ceramics, catalyst		High
Silver	9-330	•	Alloys, photography, chemical manufacturing, mirrors, electronic equipment, jewelry, equipment, catalyst, pharmaceuticals		High
Sodium	3.1-211	•	Chemical manufacturing, catalyst, coolant, non-glare lighting for highways, laboratory reagent		
Thallium	—		Alloys, glass, pesticides, photoelectric applications		High
Titanium	—		Alloys, structural materials, abrasives, coatings		Low
Vanadium	243	•	Alloys, catalysts, target material for x-rays		High, moderate
Zinc	0.1-240	•	Alloys, electroplating, electronics, automotive parts, fungicides, roofing, cable wrappings, nutrition		Moderate
Nonmetals and anions					
Ammonia	1-900	•	Fertilizers, chemical manufacturing, refrigerants, synthetic fibers, fuels, dyestuffs		
Boron	—	•	Alloys, fibers and filaments, semi-conductors, propellants		
Chlorides	1.0-49,500	•	Chemical manufacturing, water purification, shrink-proofing, flame-retardants, food processing		
Cyanides	1.05-14	•	Polymer production (heavy duty tires), coatings, metallurgy, pesticides		High
Fluorides	0.1-250	•	Toothpastes and other dentrifices, additive to drinking water		Moderate
Nitrates	1.4-433	•	Fertilizers, food preservatives		
Nitrites	—	•	Fertilizers, food preservatives		
Phosphates	0.4-33		Detergents, fertilizers, food additives		
Sulfates	0.2-32,318	•	Fertilizers, pesticides		
Sulfites	—		Pulp production and processing, food preservatives		

Table 1.—Substances Known to Occur in Groundwater, Ranges of Detected Concentrations, Exceeded Standards, Examples of Uses, and Quantitative Estimates of Carcinogenic Potency and Noncarcinogenic Toxicity[a]—continued

Contaminant	Concentration[b]	Standard[c]	Examples of uses[d]	Carcinogenic potency[e,f]	Noncarcinogenic toxicity[e,g]
Micro-organisms	(parts per million)				
Bacteria (coliform)	—	•			
Viruses	—				
Radionuclides	(picocuries per milliliter)				
Cesium 137	—		Gamma radiation source for certain foods		
Chromium 51	—		Diagnosis of blood volume, blood cell life, cardiac output, etc.		
Cobalt 60	6.4		Radiation therapy, irradiation, radiographic testing, research		
Iodine 131	—		Medical diagnosis, therapy, leak detection, tracers (e.g., to study efficiency of mixing pulp fibers, chemical reactions, and thermal stability of additives to food products), measuring film thicknesses		
Iron 59	—		Medicine, tracer		
Lead 210	—		NA[i]		
Phosphorus 32	—		Tracer, medical treatment, industrial measurements (e.g., tire tread wear and thickness of films and ink)		
Plutonium 238, 243	—		Energy source, weaponry		
Radium 226	0.8-25	*	Medical treatment, radiography		
Radium 228	12.5		NA[i]		
Radon 222	—	•	Medicine, leak detection, radiography, flow rate measurement		
Ruthenium 106	—		Catalyst		
Scandium 46	—		Tracer studies, leak detection, semi-conductors		
Strontium 90	0.817	•	Medicine, industrial applications (e.g., measuring thicknesses, density control)		
Thorium 270	—		NA[i]		
Tritium	150-353	•	Tracer, luminous instrument dials		
Uranium 238	10-500	*	Nuclear reactors		
Zinc 65	—		Industrial tracer (e.g., to study wear in alloys, galvanizing, body metabolism, function of oil additives in lubricating oils)		
Zirconium 95	—		NA[i]		

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[a] Based on Abrams, et al., 1975; Bryant, et al., 1983; Harris, et al., n.d.; O'Brien and Fisher, 1983; Tucker, 1981; University of Oklahoma, 1983; Hawley, 1977; Considine and Considine, 1983; Lewis and Tatken, 1980; and Windholz, et al., 1982.

[b] Concentrations represent single reported concentrations or ranges of reported groundwater or domestic well concentrations from references surveyed; they generally do not include concentrations at hazardous waste sites. Dash (—) indicates contaminant detected but concentration not reported. Note that units differ among categories; units are defined at the beginning of each contaminant category.

[c] Solid bullet means tha. at least one type of standard exists for the substance. Asterisk means that at least one standard is known to have been exceeded. Note that these refer to standards for individual substances; standards for groups of substances or other measurements such as BOD are listed in app. C.

[d] Listed uses are primarily industrial applications. Some substances occur naturally in groundwater and may not be a result of human activities.

[e] Absence of an entry does not necessarily mean that no adverse health effects are associated with that substance; rather, entries reflect data available to OTA. In addition, if a value was found for carcinogenic potency of a substance, no search for non-carcinogenic toxicity of that substance was made.

[f] Carcinogenic potency is measured either according to unit risks developed by EPA Carcinogen Assessment Group or according to estimated unit risk based on assessment by EPA Office of Pesticides and Toxic Substances (as reported in Environ Corp., 1983); carcinogens are listed only if peer-reviewed unit risk data are available. Unit risk = risk per unit of exposure, where unit of exposure is defined as lifetime average daily intake. Estimates of lifetime risk are obtained by multiplying unit risk by actual exposure. Potency categories are defined as (Environ. Corp., 1983):

High potency = unit risk greater than 5 $(mg/kg/day)^{-1}$

Medium potency = unit risk equal to 0.1-5 $(mg/kg/day)^{-1}$

Low potency = unit risk less than 0.1 $(mg/kg/day)^{-1}$

[g] Noncarcinogenic toxicity is measured by Minimum Effective Dose (MED, the minimum dose known to cause adverse impact; Environ Corp., 1983):

High = MED less than 10 mg/kg body weight/day

Moderate = MED 10-100 mg/kg body weight/day

Low = MED greater than 100 mg/kg body weight/day.

[h] Value for combined anthracene and phenanthrene.

[i] NA — Information on use not available in standard references that were consulted.

[j] Value for combined lignin and tannin.

ment is not easily linked to substances found in groundwater. Adverse effects and toxicity are discussed below. With respect to exposure, five possible pathways of human exposure have been identified (Environ Corp., 1983):

1. direct ingestion through drinking;
2. inhalation of contaminants (e.g., during showering);
3. skin absorption from water;
4. ingestion of contaminated food; and
5. skin absorption from contaminated soil.

Except for drinking water containing known levels of substances, there appear to be no general models available for estimating exposure through these routes.

Adverse Impacts of Chemicals

Many of the chemicals detected in groundwater are known or suspected to cause a variety of adverse health effects, including depression of central nervous system functions, liver and kidney damage, and eye and skin irritation. Some of these chemicals are known or suspected human carcinogens. The discussion below summarizes the known adverse effects of individual chemicals found in groundwater; the data upon which the summary is based are shown in appendix A.2.

Much of the data reviewed below concerning the effects of chemicals is derived from experimental studies on laboratory animals, but some information (e.g., acute effects such as eye and skin irritation, some cancers) is based on studies of human populations. The inference of human health effects from animal studies is controversial and is reviewed elsewhere (Environ Corp., 1983). However, for many chemicals, data from laboratory studies are the *only* means available for assessing potential impacts upon humans. Although there is usually no direct, conclusive evidence that these effects are induced at the concentrations at which these chemicals are detected in groundwater, a variety of information—qualitative human health studies conducted at sites of groundwater contamination (e.g., at Hardeman County, TN; Harris, et al., no date), data on human health impacts of specific chemicals (whether studied directly in humans or indirectly in laboratory animals), and much anecdotal information—suggests that the consumption of groundwater contaminated with chemicals can result in acute, subchronic, and chronic human health impacts. An important recent study shows a statistically significant relationship between two wells contaminated with chloroform and TCE and elevated leukemia and birth defect rates in Woburn, MA (reported in Science News, 1984).

Apart from the controversial nature of laboratory data, the information in appendix A.2 is a limited data base because:

- not all chemicals have been tested for all impacts,
- documentation is not available for cases in which specific impacts were *not* observed during studies of specific chemicals,
- chemicals that dominate the list of potential health effects are the ones that have been most thoroughly studied, and
- the data were obtained from secondary sources.

Thus the purpose of appendix A.2 is not to establish either that effects will be realized with certainty in exposed human populations or the probability of their occurrence. Rather, the information shown should be viewed as an indication of the nature of potential human health impacts from substances in groundwater.

A given effect can be caused by numerous chemicals (see app. A.2). The effects associated with the largest numbers of chemicals include (in decreasing order of the number of chemicals known to cause these effects): eye and skin irritation, effects on the central nervous system, liver damage, lung and respiratory tract effects, kidney damage, cancers, and genetic mutation. Of these effects, and depending on dosage, **central nervous system (CNS) damage, liver and kidney damage, and cancers may be the most commonly expected serious forms of adverse health impacts associated with known groundwater chemical contaminants** (Environ Corp., 1983). More specifically:

1. Liver, kidney, and CNS toxicants include ethylbenzene and toluene (alkyl-substituted benzenes); carbon tetrachloride, chloroform, and TCE (halogenated aliphatic hydrocarbons); bromobenzene, PBBs, and PCBs (halo-

genated aromatic hydrocarbons); chlordane, DDT, and toxaphene (chlorinated hydrocarbon pesticides); and some heavy metals.

2. Known or suspected carcinogens listed in table 1 include 32 of the organic chemicals—chlorinated aliphatic hydrocarbons and chlorinated hydrocarbon pesticides—and 5 of the heavy metals (3 of which may be active only via inhalation). The evidence for human carcinogenicity of some substances has been obtained from human studies and is quite strong. There is very little doubt that benzene, benzidine, inorganic arsenic, vinyl chloride, chromium, and nickel are human carcinogens (the latter two, however, are not likely to be present in groundwater in their carcinogenic forms).

   Studies of experimental animals where the predominant effect is on the rodent liver provide the main evidence for carcinogenicity of chlorinated aliphatic hydrocarbons (e.g., carbon tetrachloride, chloroform, TCE, PCE, and others; note from above that vinyl chloride is an exception) and chlorinated hydrocarbon pesticides (e.g., aldrin, chlordane, DDT, dieldrin, heptachlor, toxaphene, and others). It is also possible that nitrates are transformed into nitrosamines, which are carcinogenic in laboratory animals (NAS, 1977).

   In a review of 31 substances commonly found in groundwater (Crump, et al., 1980, cited in Harris, 1983), two compounds with known human carcinogenic effects were documented. In addition, 12 compounds (including six chlorinated aliphatic hydrocarbons and four chlorinated hydrocarbon pesticides) had carcinogenic effects in at least one laboratory animal species and two compounds had effects suggestive of carcinogenicity. Despite some scientific debate on the biological relevance of these findings for humans (Environ Corp., 1983), Federal regulatory agencies consider many of these substances potential human carcinogens. One compound had no observable effects in preliminary tests, *and 14 chemicals had not even been tested in animal experiments.*

3. Only a few compounds are known to be capable of damaging the reproductive system or causing birth defects, but some of them are widely used throughout society. The major substances in this category are DBCP, vinyl chloride, EDB, benzene, toluene, and xylene (Harris, 1983) and selected chlorinated ethanes and phthalate esters, PCBs, and the chlorinated dibenzo-p-dioxins (Environ Corp., 1983).

4. Skin and eye irritation, particularly during showering and bathing, might be expected when chemicals are found in groundwater. Data suggest that these effects are reversible upon cessation of exposure.

Potential Toxicity or Potency of Chemicals

In addition to requiring information on the general adverse effects of groundwater contaminants, a standard risk assessment analysis requires information on the non-carcinogenic toxicity and carcinogenic potency of the chemicals. That is, adverse effects are associated with certain chemicals, but they are elicited at only certain dosages and/or exposure levels—and different chemicals have different abilities to elicit those effects. As part of OTA's study, chemicals found in groundwater were ranked according to their relative degree of non-carcinogenic toxicity and carcinogenic potency using dose-response data when available (see table 1; Environ Corp., 1983).[2] Three broad categories are defined: "high," "moderate," and "low"; note that the definitions shown in table 1 are different for non-carcinogenic toxicity and carcinogenic potency.

Based on these broad rankings, the following general conclusions are drawn (Environ Corp., 1983):

1. Some chemicals are of high toxicity and can elicit non-carcinogenic responses (e.g., liver, kidney, and CNS damage) at relatively low doses and/or exposure levels. These chemicals include endosulfan, endrin, and kepone (pesticides), and heavy metals (see table 1).
2. Many other chemicals with potential to affect the liver, kidney, and CNS are of low to moderate toxicity and thus require higher doses and/or exposure levels to elicit these effects.

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[2] The susceptibility of humans to various substances is also variable among individuals and is affected by factors such as age, general health, and genetic background.

These chemicals include trichlorofluoromethane, bromochloromethane, chloromethane, and 1,1-dichloroethane (halogenated aliphatic hydrocarbons), bromobenzene and dichlorobenzene (halogenated aromatic hydrocarbons), and ethylbenzene and toluene (alkyl-substituted benzenes).

3. Substances with high to moderate carcinogenic potency can elicit carcinogenic responses at relatively low doses and/or exposure levels. These chemicals include aldrin, DDT, dieldrin, and chlordane (pesticides), carbon tetrachloride, chloroform, and 1,1-dichloroethylene (halogenated aliphatic hydrocarbons), benzidine (an aromatic amine), and PCBs (halogenated aromatic hydrocarbons).

There are substantial numbers of chemicals known to occur in groundwater for which no toxicity or potency data are available (beyond some acute effects). Approximately two-thirds of the organic chemicals and one-half of the inorganic chemicals listed in table 1 may not have associated toxicity or potency data.[3] In addition, substances not generally thought of in terms of toxicity or potency (e.g., salt water, micro-organisms, or nitrates) can also contaminate aquifers, causing both health and non-health impacts.

Photo credit: State of Florida Department of Environmental Regulation

Research on health impacts will provide information now lacking about many groundwater contaminants.

Interactions Among Multiple Chemicals

One of the potentially most important, and as yet relatively unexplored, health issues of groundwater contamination is that contaminated aquifers usually contain more than one substance. **Knowledge is almost totally lacking about possible interactions among combinations of substances.** Such interactions, in which subsequent impacts are qualitatively and quantitatively different than expected (and usually greater—i.e., synergistic), are common in many chemical and biological processes (Odum, 1971).

At least one type of synergistic interaction has been identified that is of potential importance in groundwater: the liver toxicity of carbon tetrachloride, TCE, and 1,1,1-trichloroethane (halogenated aliphatic hydrocarbons) is known from animal experiments to increase greatly in the presence of alcohol. This effect has been confirmed in human case studies for carbon tetrachloride and TCE (Radike, et al., 1977; EPA, 1980a and b). Liver toxicity of TCE and PCE is also affected by Aroclor 1254, a polychlorinated biphenyl (PCB) (see NRDC, 1982; EPA, 1980c).

Biological Substances

Pathogenic biological organisms that have been found in groundwater include:

1. bacteria (e.g., typhoid, bacillary dysentery, cholera, gastroenteritis, and tuberculosis);
2. viruses (e.g., enteroviruses and hepatitis); and
3. parasites (e.g., protozoa, worms, and fungi).

The micro-organisms most frequently found in groundwater are bacteria that inhabit the gastrointestinal tract, and the most common category of disease resulting from micro-organisms in groundwater is gastrointestinal. Contaminated groundwater was identified as the cause of approximately one-half of all outbreaks of acute waterborne disease occurring in the United States from 1971 to 1977, and bacterial contamination has been the most frequently identified source of groundwater-related disease outbreaks (e.g., EPA cites 94 such outbreaks between 1945 and 1980; see Environ Corp., 1983). The potential for bacterial contamination of groundwater depends on both the survival rate of the species and characteristics of the subsurface (e.g., moisture content, pH, and temperature). Bacterial contamination most commonly results from the introduction of human (or animal) fecal material, usually when septic tanks or cesspools leak or overflow (Environ Corp., 1983).

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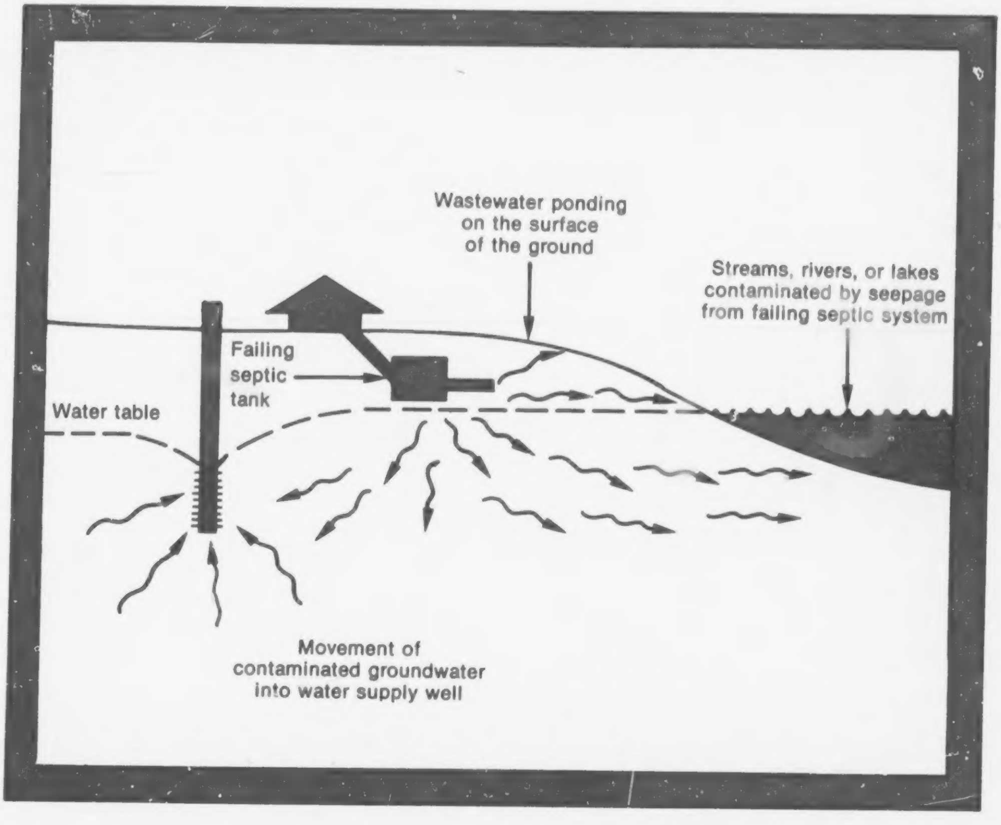
[3] Data may be available for these substances in sources not reviewed by OTA.

Viruses and parasites have been implicated in groundwater contamination incidents in relatively few instances. The low rate for viruses may be attributed to limitations in detection methods (Environ Corp., 1983). The analytical limitations regarding detection of viruses, coupled with estimates by the World Health Organization that about 60 percent of the cases of waterborne disease reported in the United States are caused by unrecognized or unknown agents, suggest that **viral contamination of drinking water (including groundwater sources) may be of greater significance than has been recognized** (Environ Corp., 1983). The principal sources of viruses in groundwater are sewage effluent (e.g., from septic tanks, cesspools, and land application practices), animal feedlots, and dairies. The factors that affect the occurrence of viruses in groundwater are complex and poorly understood; it is likely that they are similar to those for bacteria.

Radioactive Substances

Most groundwater contains trace levels of naturally occurring radioactive substances or their byproducts. The types and levels vary from area to area, depending principally on subsurface materials. In addition to natural radiation, radioactive


Wastewater ponding
on the surface
of the ground
Streams, rivers, or lakes
contaminated by seepage
from failing septic system
Failing
septic
tank
Water table
Movement of
contaminated groundwater
into water supply well

Credit: Southeast Michigan Council of Governments, 1982

Septic systems can cause both biological and chemical contamination of groundwater and surface water.

substances in groundwater can result from human activities. These sources include radioactive waste disposal sites, waste tailings and piles, and mine drainage related to uranium mining.

Health protection from radiation is a highly developed science, and data accumulated over many years link adverse health effects and exposure. Importantly, health effects are generally understood only at high exposure levels; **only in isolated circumstances are these levels of radioactivity likely to occur in groundwater.** The National Academy of Sciences, in its discussion of the health risks of radioactive drinking water (NAS, 1977), estimated total average body exposure from drinking contaminated water at less than 1 percent of total average yearly background radiation exposure received by the population (total exposure is approximately 100 mrem/year). The risk of cancer from total average natural background radiation is estimated at 4.5 to 45 fatalities per million persons per year (estimates depend on particular assumptions; NAS, 1977), including 0.6 fatal cases of bone cancer per million persons per year.

Because radioactive content can vary from average conditions, there can be situations in which doses are significantly greater than average. For example, in areas with high groundwater radium levels (e.g., 25 pCi/liter of Ra^{226} and 12.5 pCi/liter of Ra^{228}), exposure of the human skeleton could be as much as a sixfold increase (up to 600 mrem/year) over that from all natural background sources. Radiation in groundwater could thus be a serious problem in localized areas, e.g., parts of New England (Harris, 1984; Duncan, et al., 1976, cited in Prichard et al., 1983). Under the "high" groundwater radium levels mentioned above, the risk of fatal bone cancer could increase to an estimated 4.2 fatalities per million persons per year.

Radiation exposure can also cause developmental or teratogenic effects; the lowest dose at which any developmental or teratogenic effect has been reported is 1,100 mrem/year. Under "average" conditions, doses received by the population are so small that no measurable developmental or teratogenic effects from drinking radioactive groundwater would be found, even during the sensitive period of gestation (NAS, 1977).

NON-HEALTH IMPACTS

There is a general absence of both methodological experience and data on evaluating the non-health impacts—economic, environmental, and social—of groundwater contamination. Examples of these impacts are shown in table 2. Because available data are insufficient for quantifying or otherwise comparing most of these impacts, this section focuses on the nature of non-health impacts and the difficulties in their assessment.

Economic Impacts

Data about various types of economic impacts associated with groundwater contamination are generally not available (University of Oklahoma, 1983). The data that are available tend to be the direct costs of corrective action; and they either encompass such a broad range that they are difficult to interpret apart from site-specific conditions (e.g., corrective actions can cost tens of millions of dollars or more depending on site conditions), or they lack sufficient documentation (e.g., in terms of describing site conditions) for subsequent comparison and analysis. Some data may also be unobtainable because of their proprietary nature or use in litigation.

In addition to empirical difficulties, there are methodological difficulties in assessing the value of groundwater quality in terms of both the costs of contamination and the benefits of protection. Few studies are available that systematically approach an assessment of economic impacts (see Raucher, 1983; Sharefkin, et al., 1983; Reitman, 1982). These conceptual difficulties, some of them common to the assessment of impacts on other environmental media (e.g., surface water and air), include:

Table 2.—Examples of Economic, Environmental, and Social Impacts Resulting from Groundwater Contamination

Economic impacts	
Industry	Higher operation/maintenance or capital costs (e.g., for accelerated repair or replacement of damaged equipment or materials)
	Lost output from downtime during repairs, during the search for alternative water supplies, and during relocation
	Relocation costs
	Decreases in property value
	Decreases in revenue if quantity of products sold or their prices fall as a result of lower product quality
	Secondary costs (e.g., incurred by suppliers to inputs to the industry or by receivers of the output such as by processors or marketing agents)
	Legal and administrative costs
	Costs of detection, correction, and prevention activities
Agriculture	Higher operation/maintenance or capital costs (e.g., for accelerated repair or replacement of damaged equipment or materials)
	Loss of output due to damage to productivity of land (also reflected in decreases in property value)
	Lost revenue from discarding of food products unsuitable for consumption
	Loss of output due to injury or death to perennial plants and trees
	Decreases in livestock productivity, including illness and death
	Secondary costs (e.g., incurred by suppliers of inputs to agriculture or by receivers of output)
	Legal and administrative costs
	Costs of detection, correction, and prevention activities
Households	Higher operation/maintenance or capital costs (e.g., for cleaning, replacement, and/or rehabilitation of damaged pipes, plumbing, appliances)
	Decreased value of residential property
	Relocation expenses, including search costs, higher purchase prices, higher interest rates and fees, and moving costs
	Secondary costs (e.g., contraction or expansion of commercial activities)
	Loss of income due to sickness
	Legal costs
	Costs of detection, correction, and prevention activities (e.g., pre-treatment and purchase of bottled water)
Municipalities	Lost receipts from property, sales, or income taxes
	Re-allocation of additional resources to provide emergency services
	Costs of procuring alternative supplies
	Legal and administrative costs
	Detection, correction, and prevention activities
Environmental impacts	
Aesthetics	Odor
	Taste
	Appearance
Surface water contamination by groundwater	
Biota	Damage to vegetation, waterfowl, and aquatic life
	Contamination of fish
Air pollution	
Soil contamination	
Social impacts	
Psychological stress	
Inconvenience	
Social disruption	

SOURCE: Office of Technology Assessment.

- determination of the effects of various activities and practices on groundwater quality;
- determination of the effects of changes in groundwater quality on groundwater use;
- lack of a perfectly competitive economic marketplace for valuing groundwater quality;
- selection of an appropriate time horizon for the analysis and an appropriate discount rate for the time value of money; and
- assessment of the cost and effectiveness of various approaches to detection, correction, and prevention of groundwater contamination.

The economic damages resulting from groundwater contamination shown in table 3 illustrate the types and magnitude of documented costs. Data are easiest to obtain for perceptible, short-term effects on users that are reflected in the marketplace. Importantly, although the real value lost to the Nation from any one incident may not be significant compared to, say the gross national product, **the economic costs of groundwater contamination are significant if the costs for all incidents are combined and if the time over which these costs will be incurred is considered.** In addition, the costs to the Nation associated with the contamination of many aquifers may well exceed the sum of the costs associated with individual aquifers—e.g., if there is widespread loss of potable drinking water or of agricultural produce. Further, **the economic damages from any one incident may be significant from the perspective of the populations and users affected.** For example, cash-flow imbalances or other dislocations (e.g., layoffs) can result, especially during emergencies when impacts may not be anticipated or planned for.

Environmental and Social Impacts

Contaminated groundwater causes diverse environmental and social impacts; they are generally not quantifiable and little documentation is available.

Because groundwater provides a significant portion of baseflow to streams, the potential for adverse impacts on surface water quality may be large, especially during periods of low rainfall when dilution is minimal. Changes in the quantity of groundwater also influence the quality of groundwater (e.g., the pumping of groundwater can induce the migration of contaminants). The extent of other environmental impacts is unknown; some cases document damage to fish, vegetation, and wildlife. The potential for groundwater contaminants (e.g., volatile organics) to enter the atmosphere in the vicinity of certain sources (e.g., landfills) or from volatilization during showering has now been recognized.

Social impacts are related largely to the anxiety caused by fear and uncertainty about exposure to contaminants. Exposure can occur unknowingly because many contaminants are odorless, colorless, and tasteless. Exposure to contaminants occurs over many years and via many pathways, including drinking contaminated water, eating foods that have been in contact with contaminated groundwater, bathing in contaminated water, and breathing contaminants when they volatilize in the shower. Social impacts also arise from decreased property values, and from lost income because of illness, relocation, and inconvenience (e.g., in procuring alternative water supplies).

CONCENTRATION AND FREQUENCY OF SUBSTANCES FOUND IN GROUNDWATER

Concentration of Substances in Groundwater

A substance is "detected" or "reported" if its concentration sufficiently exceeds the detection limits of sampling and measurement equipment so that its presence is verifiable. Detection limits (typically referred to as "trace levels") imply that values below the measurement threshold will not be reported as positive even if substances are in fact present at lower concentrations.

A wide range of concentrations of various substances has been found in groundwater (table 1). The most important conclusions about the concentration data are:

- concentrations of substances in groundwater are site-specific and thus are highly variable spatially;
- concentrations are highly variable temporally—they may fluctuate at a particular site by a factor of 10 during the course of a year (Har-

Table 3.—Examples of Economic Costs Resulting From Contaminated Groundwater[a]

Location	Contaminants	Nature of costs	Direct costs incurred	Documentation
Canton, CT	Carbon tetrachloride, methylethylketone, trichloroethythene, chloroform	Well closings; extension of water lines to affected areas	$145,000–379,000	CRS, 1960a
Oscoda, MI	Trichloroethylene	Well closings; provision of new source of water	$140,000	CRS, 1980a
South Brunswick, NJ	Chloroform, toluene, xylene, trichloroethane, trichloroethylene	Well closings; extension of municipal water lines to affected area	$300,000	CRS, 1980a
Cohansey Aquifer, NJ	Wastes from manufacture of organic chemicals, plastics, resin	Well closings (148); removal of drums; interim emergency water supply (via tanker trucks); drilling of new wells; extension of public water supply (60% of total monetary costs)	$417,000 (Residential cost of water increased from an average of $45/year to $75/year)	U.S. EPA, 1976 CRS, 1980b
Miller County, AR	Brine contamination from oil and gas activities	Loss of irrigation well	$4,000	Fryberger, 1972
		Partial rice crop loss	$36,000	
		Estimated loss in profits for changing from irrigated to nonirrigated crops	$150/acre/year for rice $35/acre/year for cotton $20/acre/year for soybeans	
38 communities in 11 Midwestern States[c]	Mineral content	Reduced service lives of household plumbing and appliances	Increased annual capital cost per household of 40% as total dissolved solids increase from 250 ppm to 1,750 ppm	Patterson, et al., 1968
Atlantic City, NJ	Chemical wastes (Price's Landfill)	Estimated cost of new well field to replace contaminated wells	$2 million	As reported in Sharefkin, et al., 1983
		Cost of alternative water supply to 35 private residences	$250,000	
Orange County, CA[d]	Mineral content	Estimated cost of reduced service lives of household plumbing and appliances	$6.5 million total annual capital cost	Orange County Water District, 1982
		Estimated average annual cost of water softeners or increased cost of cleaning products	$12.3 million	
		Estimated average costs of using bottled water	$2.2 million	
Montana	Salinity	Loss of farm income	$5 million per year	Miller, 1980
San Joaquin Valley, CA	Salinity	Loss of farm income	$31.2 million per year	Sheridan, 1981
Auburn, MA	Unspecified chemicals	Alternative water supply for affected area	$180,000	U.S. House of Representatives, 1980
Lathrop, CA	Pesticides	Purchase of water by residents	$3–5 per 5 gallons	CRS, 1980b
		Connection to district water supply	$150 per connection, monthly operating costs of $4–10	
Jackson Township, NJ	Chloroform, methyl chloride, benzene, toluene, trichloroethylene, ethylbenzene, acetone	Costs of planned water system to replace closing of 100 wells	$1.2 million	CRS, 1980a

[a] Based on University of Oklahoma, 1983.
[b] Costs shown are not comparable because they are not measured in constant dollars.
[c] Almost all these communities obtain their primary water supply from groundwater.
[d] Costs are those associated with using higher salinity (surface) water from the Colorado River as opposed to water from the State Water Project.

SOURCE: Office of Technology Assessment.

ris, et al., no date), and they may vary from day to day (Harris, 1984);

- concentrations of substances are often many times higher in groundwater than in surface water; and
- higher concentrations of substances are typically found near the site of their release (Westerhoff, et al., 1982), especially if that site contains concentrated amounts of the substance, sources are numerous, and/or the site is characterized by relatively permeable soils.

A number of surveys focusing on *public* drinking water wells have been conducted by the States and the Federal Government in the last 10 years—including the early Environmental Protection Agency (EPA) National Organics Reconnaissance Survey (NORS) and National Organics Monitoring Survey (NOMS) and, more recently, the Community Water Supply Survey (CWSS) and Ground Water Supply Survey (GWSS).[4] Efforts in these studies were oriented toward detection of volatile organic chemicals (VOCs), as opposed to non-VOCs (NAS, 1977). These studies show that **volatile organic compounds are frequently present at detectable concentrations in public drinking water wells.**[5] The studies also reveal that **concentrations of compounds in groundwater are often much higher than in surface water;** for example, TCE, toluene, and 1,1,1-trichloroethane are up to 1,000 times more concentrated in groundwater than in surface water (Burmaster, et al., 1982).[6]

The National Inorganic and Radionuclides Survey (NIRS) is an ongoing EPA study of groundwater-supplied community water systems; 38 inorganics (26 of which have already been detected in groundwater), 4 radionuclides (all previously detected in groundwater), and 2 common measures of radioactivity are the focus of this investigation.

Because of the site-specific nature of groundwater contamination, it is not possible to draw more detailed conclusions about or to predict typical contaminant concentrations. At best, concentration data indicate the severity of site-specific contamination problems and immediate local risks to public health and the environment (see the sections on *Standards* and *Health Impacts*). Such data are also essential to determine the suitability of alternative corrective actions (see ch. 8).

Generalizations about concentration data at any level more aggregated than at an individual site are highly tentative. Systematic collection of data in space or time can show how concentrations vary in an area and can provide historical information, thus establishing contamination trends for a particular source and/or type of hydrogeologic setting. In all cases, however, the concentration data are snapshots at one point in time and thus do not take into account the dynamics of system behavior.

Frequency of Occurrence of Substances in Groundwater

Frequency of occurrence generally refers to the number of positive samples (i.e., number for which the substance of concern is detected) in the total number of samples tested. Like concentration data, frequency data can be biased by sampling procedures and analytical detection limits (University of Oklahoma, 1983; Westrick, et al., 1983). In addition, data are not usually collected with sufficient detail for frequency analysis (e.g., detection limits of the measuring instrumentation are often not specified), and there may be no information available on frequency distributions. Most importantly, there is often no attempt to link frequency data with concentration data; thus a "positive" sample implies that the substance is detectable, but it does not indicate the concentration.

Interpretation of frequency data is more meaningful if information is also available about such factors as historical land uses and sources. At least at the site-specific level, frequency data can give an impression of the pervasiveness of substances in groundwater. From a regional or national perspective, however, interpretation of frequency data becomes much more difficult. Nationwide frequency studies would require extensive sampling (hundreds to thousands of sites) and, like concentration studies, would provide only snapshots.

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[4] The National Statistical Assessment of Rural Water Conditions (EPA, 1984) is EPA's response to a congressional mandate under Section 3(a) of the Safe Drinking Water Act, for a one-time evaluation of characteristics of drinking water supplies, including water quality, in rural households. This is the first national sampling of *private* water supplies.

Results suggest water quality problems of greater magnitude and prevalence (especially for metals) than had generally been expected, based on data from monitoring community water systems and from other studies. Bacterial contamination was the most prevalent problem. Water quality sampling for organic substances was restricted to substances covered under National Interim Primary Drinking Water Regulations: Lindane, Methoxychlor, Toxaphene, 2,4-D, and 2,4,5-TP. No significant problems were detected from organic substances.

[5] Projections of the number of groundwater and surface water systems in the United States that have concentrations of individual VOCs exceeding 5 μg/l are also available (Coniglio, 1982).

[6] This may not be true for the trihalogenated methanes (THMs; Harris, 1983)—chloroform, bromoform, bromodichloromethane, dibromochloromethane.

With these limitations in mind, data concerning the frequency of occurrence for specific chemicals are summarized in appendix A.3. The national surveys listed in the section on *Concentration of Substances in Groundwater* (NORS, NOMS, CWSS, GWSS), the National Screening Program for Organics in Drinking Water (NSP), and some State surveys have all yielded data on the frequency of organic chemicals in groundwater-supplied drinking water. Information on the percentage of total groundwater samples in Federal surveys which contained detectable levels of VOCs is summarized by Coniglio (1982).

General conclusions about the frequency data are:

- several organic chemicals associated with chlorinated solvents, especially TCE and PCE, have frequently been detected in groundwater contamination incidents;
- public drinking water systems relying on groundwater are frequently contaminated with VOCs; and
- two or more VOCs are frequently detected simultaneously in groundwater supplies.

In studies of drinking water wells conducted by 18 States, frequencies of detection of various VOCs were compiled for both random and non-random samples (CEQ, 1981). For the most common chemicals in the random samples, frequency of detection ranged among the States from 1.7-11.3 percent for TCE and from 3.6-4.5 percent for 1,1-dichloroethane. Random samples both are more indicative of general conditions and generate more conservative estimates than non-random samples.

The two most recent Federal studies (CWSS and GWSS) provide much information regarding frequency of VOCs in groundwater. Information from the CWSS indicated that 15 percent of public water systems relying on groundwater contained at least one VOC; VOCs were detected in 45 percent of the public water systems serving more than 10,000 people and in 12 percent of the more numerous public water systems serving fewer than 10,000 people. Because the samples were 1-2 years old at the time of analysis, some VOCs may have degraded; thus, these percentages are regarded as minimum estimates (Brass, et al., 1981, cited in NRDC, 1982).

The GWSS (Westrick, et al., 1983) provides information on the frequency with which one or more VOCs were detected in groundwater samples. In the GWSS, random samples of groundwater supplies from public water systems were collected from 466 randomly selected communities. The percentage of random samples with one or more VOCs detected was 16.8 percent for small systems (serving fewer than 10,000 people) and 27.9 percent for large systems (serving more than 10,000 people). TCE and PCE were detected in 3.2 percent and 4.6 percent of the random samples from small systems, respectively, and both were detected in 11.3 percent of the random samples from large systems. More importantly, the percentage of random samples with two or more VOCs present was 6.8 percent for small systems and 13.4 percent for large systems. An additional part of the survey focused on non-random supplies selected by State agencies.

Concentration and Frequency Data in Relation to Governmental Standards

Evaluation of health risks associated with groundwater contamination requires, among other things, information concerning both frequency and concentration of substances—specifically, the frequency with which groundwater contains one or more substances at concentrations exceeding levels that are considered unsafe. Standards promulgated by government agencies specify those limits above which the presence of a substance is considered unsafe; they thus serve as a gauge of the potential impacts of contamination. Concentration data alone can reveal potential problems, but only if they can be compared with standards or health impact data related to those specific concentrations.

No Federal standards have been developed specifically for substances found in groundwater. But various Federal standards and guidelines—some developed for drinking water—have been applied to groundwater. These include National Interim Drinking Water Regulations (Primary and Secondary), Health Advisories, and Ambient Water Quality Criteria. In addition, individual States have developed standards which they are applying to groundwater, including State drinking water standards and State groundwater standards (see chs. 3 and 4 and app. C.3 for additional information related to standards).

Standards or guidelines of some type (State or Federal) have been promulgated for less than one-half the substances that have been detected in groundwater (refer to table 1). Although Federal standards or guidelines exist for over 60 substances, there are only 22 enforceable standards (established by the National Interim Primary Drinking Water Regulations) and of these, 18 are for individual substances. An additional six Federal standards are non-enforceable under the Secondary Regulations; remaining standards or guidelines are Health Advisories or Ambient Water Quality Criteria. Over 150 substances and other quality indicators have State standards; less than one-half of them also have some type of Federal standard or guideline.

Because there is no consistent approach to the development of standards, because different standards are used by different Federal and State agencies, and because standards do not exist for many substances, **people in different States do not receive a uniform level of health protection against groundwater contaminants.** For example, some States (especially in the Northeast, but also in other parts of the country) have closed contaminated drinking water wells in order to prevent human exposure to specific chemicals (e.g., TCE, PCE, dichloroethane, benzene, chloroform, toluene, and vinyl chloride; Environ Corp., 1983). Concentrations of the chemicals in the closed wells almost always exceeded Ambient Water Quality Criteria, but the levels at which the wells were closed varied greatly from State to State. For example, wells in New York, Rhode Island, and Massachusetts were closed at levels of tetrachloroethylene ranging from 1-61 parts per billion (Ambient Water Quality Criterion = 0.8 ppb); and wells in New York and Rhode Island were closed at levels of 1,1,1-trichloroethane ranging from 3-1400 ppb (Ambient Water Quality Criterion = 18.4 ppb). Although these data indicate the levels at which wells were closed, they do not indicate the minimum threshold concentrations that would have elicited well-closing decisions (Environ Corp., 1983).

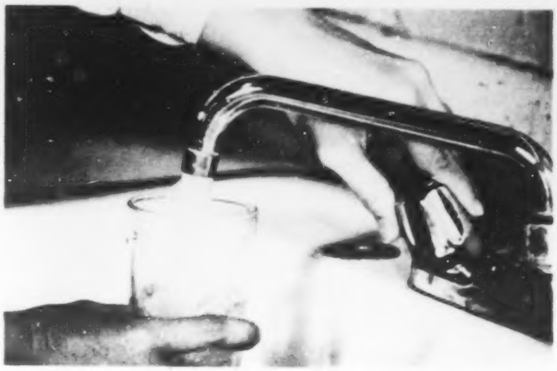

Photo credit: State of Florida Department of Environmental Regulation

About one-half of the Nation's population depends on groundwater for drinking, and the level of health protection against groundwater contaminants varies from State to State.

Theoretically, frequency data could be linked with concentration data and various standards to ascertain the percentage of contamination incidents in which some type of standard is exceeded. If the standard reflects an exposure level that could result in adverse health effects, then this type of analysis would yield information on the frequency with which the public is exposed to unsafe concentrations of contaminants in groundwater. In general, both concentration and frequency data are usually not reported in enough detail for such an analysis.

OTA's study attempted such an analysis, as a first approximation, for examples with sufficient data. Documentation showed 38 organic chemicals, 25 inorganic chemicals, and two radionuclides for which concentrations in at least one groundwater sample are known to have exceeded one or more of the above types of standards or guidelines (see app. A.4 for details of which standards or guidelines have been exceeded). Of these 65 substances, 14 (3 organics, 10 inorganics, and 1 radionuclide) involve National Interim Primary Drinking Water Regulations, and an additional 5 inorganic chemicals involve Secondary Regulations. In most cases where standards or guidelines were exceeded, State standards or Ambient Water Quality Criteria were involved.

Frequency and concentration data are available for 13 of the 38 organic chemicals known to exceed some standard or guideline in at least one sample; for none of these 13 compounds have the National Interim Primary or Secondary Drinking Water Regulations been promulgated. Calculations indicate that 4 of the 13 compounds are known to exceed at least one type of standard or guideline in 5-10 percent of groundwater contamination incidents (the type of standard or guideline exceeded is shown in parentheses in the following list):

1. carbon tetrachloride (State groundwater and Ambient Water Quality);
2. 1,1-dichloroethylene (Ambient Water Quality);
3. tetrachloroethylene (Ambient Water Quality); and
4. trichloroethylene (Ambient Water Quality).

This list is not intended to be exhaustive; rather, it documents situations where substances are known to exceed specified standards or guidelines frequently.

POTENTIAL BUT AS YET UNDETECTED SUBSTANCES IN GROUNDWATER

Many substances have the potential to enter groundwater because of their molecular properties and association with sources (see the section on *Association of Substances Found in Groundwater With Sources,* which follows); **they may already be present in groundwater but have not yet been detected.** This study has been unable to determine whether these substances have not yet been detected because they are not being looked for, or are being looked for but have not been found. A number of them are known or are suspected to exhibit toxic properties. Table 4 presents some generalizations about potential groundwater contaminants that could have serious health effects; these generalizations are derived primarily from animal experiments. Table 4 should not be viewed as either exhaustive or definitive. It appears that some, but not all, of the contaminants of potential concern can be detected with standardized analytical methods (Environ Corp., 1983).

TYPES OF SOURCES AND ASSOCIATED SUBSTANCES

Types of Sources

The quality of groundwater is altered by a wide variety of human activities and naturally occurring situations. Sources are points along the pathways that substances travel as they flow through society, where the substances can be released into groundwater. To illustrate, substances can be stored in or flow through sources in a variety of ways, from the storage of raw materials (e.g., materials stockpiles) to manufacturing (e.g., product storage) to distribution (e.g., pipelines) to use (e.g., pesticide applications) to disposal (which can take place almost anywhere in the process).

OTA's study has identified 33 sources known to have contaminated groundwater and has categorized them based on the nature of their release of substances to groundwater (table 5). It is important to note that these categories are for the convenience of discussion. Depending on emphasis, a source could be categorized in another way. For example, non-waste injection wells (for enhanced recovery and artificial recharge) could be placed in Categories I or V. In addition, sources interact with each other—a leak from an aboveground storage tank could result in substances entering groundwater directly (Category II) or entering urban runoff and, subsequently, groundwater (Category IV).

Table 4.—Potential Groundwater Contaminants Displaying Serious Adverse Health Effects[a]

Compound or class	Potential effects
Acrylonitrile	Carcinogenicity
Alkyl lead compounds	Neurotoxicity; damage to kidneys and hematopoietic system
Alkylamines and alkanolamines (alkyl polyamines, secondary amines)	Allergic sensitization; liver and kidney injury; potential to form carcinogenic N-nitrosomines
Carbon disulfide	Neurotoxicity
Dimethyl sulfate	Carcinogenicity; mutagenicity
n-Hexane	Neurotoxicity
Mercaptans	CNS depression; liver and kidney damage
N-Nitrosamines	Carcinogenicity
Pesticides which are not included in Table 1.1	Neurotoxicity; enzyme inhibition
Phenols which are not included in Table 1.1	Neurotoxicity; variety of systemic effects
Propylene oxide	Suspect carcinogenicity; mutagenicity

[a] Additional details in Environ Corp., 1983.

SOURCE: Office of Technology Assessment.

Other categorization schemes are also possible (e.g., according to the nature of the user: agricultural, industrial, domestic, and municipal; or the physical location of the source: above the land surface, below the land surface and above the groundwater table, and below the groundwater table). However, classification based on discharge characteristics has the advantage of identifying and characterizing the *entry* of substances into the groundwater system. The points-of-entry, in turn, are places where actions can be taken to discover and alter the entry—i.e., to detect, correct, and prevent contamination.

Three general conclusions can be reached from this categorization:

1. There is a great diversity of sources, and they are associated with a broad range of industrial, agricultural, commercial, and domestic activities. **Both wastes and non-wastes are potential contaminants of groundwater.** However, most attention has been focused on wastes, particularly hazardous wastes, from point sources or clusters of point sources. (A "point" source is an easily identified facility, such as a landfill or impoundment.)
2. Only a few source types (Category I) are specifically designed to discharge substances (i.e., wastes) into the subsurface.
3. Non-waste releases result from some sources designed to retain non-waste products (Categories II and III) and as a consequence of other activities (Category IV) or altered flow patterns (Category V).

Association of Substances Found in Groundwater With Sources

The occurrence of substances in groundwater and an understanding of how, why, and where they are present are directly related to their use and/or disposition. One way of approaching this topic is to examine the association of various substances with specific sources.

Rather than examine all substances shown in table 1 individually, this study relates nine general classes of substances to specific sources[7] (table 6). Classes of substances with the *potential* to be found in association with a source are also indicated. Table 6 does not represent a comprehensive survey of the literature, even though one was attempted. New information about actual contamination incidents is being obtained continually, especially as the States survey their groundwater resources or

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[7] The selection of the nine groupings is based on three fundamental features exhibited by all molecules (Woodward-Clyde Consultants, 1983): 1) elemental composition (i.e., elements and their frequency of occurrence in a molecule); 2) functional group (i.e., the arrangement of elements into stable combinations); and 3) structure (i.e., the spatial arrangement of elements).

A substance, in turn, is placed in a grouping if two conditions are met: first, at least a piece of the substance must possess the composition, function, and structure of the grouping, and second, that piece of the substance must be the most readily discernible by measurement techniques (see ch. 5). Thus, a highly complex chemical compound (e.g., multifunctional organic) could be placed into several groupings on the basis of the first condition but, if there are such ambiguities, the following hierarchy would be followed for its categorization based on the second condition: element-containing dominates aromatic, aromatic dominates oxygenated, and oxygenated dominates other hydrocarbons. In addition, biologicals and radionuclides are listed as separate groupings since these properties in themselves are sufficient for their detection; these groupings would dominate all other groupings in the hierarchy. The groupings shown deviate from conventional approaches to contaminant categorization: these groupings are based on molecular properties as well as detectability; conventional categories are based strictly on molecular properties (and thus tend to be more detailed).

Table 5.—Sources of Groundwater Contamination

Category I—Sources designed to discharge substances
- Subsurface percolation (e.g., septic tanks and cesspools)
- Injection wells
  - Hazardous waste
  - Non-hazardous waste (e.g., brine disposal and drainage)
  - Non-waste (e.g., enhanced recovery, artificial recharge, solution mining, and in-situ mining)
- Land application
  - Wastewater (e.g., spray irrigation)
  - Wastewater byproducts (e.g., sludge)
  - Hazardous waste
  - Non-hazardous waste

Category II—Sources designed to store, treat, and/or dispose of substances; discharge through unplanned release
- Landfills
  - Industrial hazardous waste
  - Industrial non-hazardous waste
  - Municipal sanitary
- Open dumps, including illegal dumping (waste)
- Residential (or local) disposal (waste)
- Surface impoundments
  - Hazardous waste
  - Non-hazardous waste
- Waste tailings
- Waste piles
  - Hazardous waste
  - Non-hazardous waste
- Materials stockpiles (non-waste)
- Graveyards
- Animal burial
- Aboveground storage tanks
  - Hazardous waste
  - Non-hazardous waste
  - Non-waste
- Underground storage tanks
  - Hazardous waste
  - Non-hazardous waste
  - Non-waste
- Containers
  - Hazardous waste
  - Non-hazardous waste
  - Non-waste
- Open burning and detonation sites
- Radioactive disposal sites

Category III—Sources designed to retain substances during transport or transmission
- Pipelines
  - Hazardous waste
  - Non-hazardous waste
  - Non-waste
- Materials transport and transfer operations
  - Hazardous waste
  - Non-hazardous waste
  - Non-waste

Category IV—Sources discharging substances as consequence of other planned activities
- Irrigation practices (e.g., return flow)
- Pesticide applications
- Fertilizer applications
- Animal feeding operations
- De-icing salts applications
- Urban runoff
- Percolation of atmospheric pollutants
- Mining and mine drainage
  - Surface mine-related
  - Underground mine-related

Category V—Sources providing conduit or inducing discharge through altered flow patterns
- Production wells
  - Oil (and gas) wells
  - Geothermal and heat recovery wells
  - Water supply wells
- Other wells (non-waste)
  - Monitoring wells
  - Exploration wells
- Construction excavation

Category VI—Naturally occurring sources whose discharge is created and/or exacerbated by human activity
- Groundwater—surface water interactions
- Natural leaching
- Salt-water intrusion/brackish water upconing (or intrusion of other poor-quality natural water)

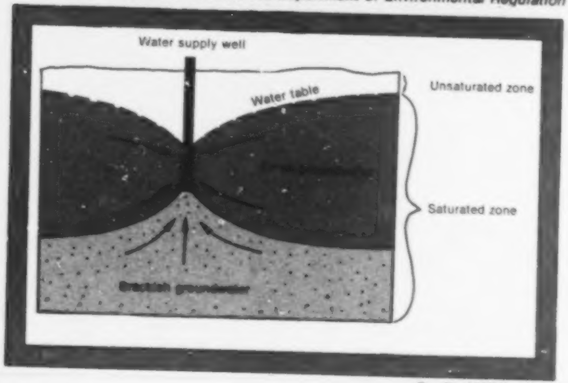
SOURCE: Office of Technology Assessment.

respond to contamination incidents, inventory sources, and monitor supplies, and as efforts are undertaken to recover and/or remove substances prior to their entry into the groundwater.

Four general conclusions can be drawn from this table:

1. A diversity of classes of substances is associated with known sources of contamination. The most common are the metals/cations and non-metals/anions, followed by hydrocarbons with specific elements (e.g., pesticides and chlorinated solvents), miscellaneous hydrocarbons (e.g., fuels), and radionuclides.
2. The association of substances with specific sources often varies according to the nature of the use and disposal of substances by different segments of society. For example, pesticides may enter groundwater from the storage tanks of manufacturers, from aerial spraying during agricultural operations, and from residential disposal in backyards. In contrast, because of their design and operating constraints (see app. A.5), radioactive disposal

Photo credit: State of Florida Department of Environmental Regulation



Credit: USGS, 1983b

Poorly constructed and maintained or abandoned wells can provide a conduit for the introduction of contaminants into groundwater because of, for example, the migration of water through corroded casings. In this case, uncontrolled discharge from an artesian well is causing brackish water upconing.

sites are not likely to contain many organic chemicals. In addition, substances associated with a source are not necessarily found at every facility of a given source type, and they can vary from facility to facility and over time at a given facility. The essential conclusion is that **generalizations about the association of substances with sources are not possible** — specific substances associated with a single source depend on past and present uses, and thus the association of substances with sources is highly site-specific.

3. Almost all sources are likely to release simultaneously a number of substances with very different properties. Eight sources (subsurface percolation, disposal wells, land application, landfills, open dumps, residential disposal, surface impoundments, and underground storage tanks) have already been associated with substances from five or more classes, and an additional nine sources have a similar potential (table 6). Even if only one class of substances is involved in a particular situation, many individual substances within that class could be present, and their properties (e.g., toxicity) could vary.
4. For sources associated with particular activities (e.g., agricultural practices and materials storage), fewer classes of substances are likely to be found combined. Even then, however, a broad range of substances may be present in groundwater, depending on past and present land uses.

Holiday
House & Ke Spr
REAL-KILL
House Ga Bu
LUSTER BATH
ORTHO
white

Photo credit: U.S. Environmental Protection Agency

Residential disposal as a source of groundwater contamination involves the indiscriminant disposal of household products.

FACTORS INFLUENCING A SOURCE'S POTENTIAL TO CONTAMINATE GROUNDWATER

The extent to which a source has the potential to contribute to groundwater contamination depends on factors that characterize both the general type of facility or activity (e.g., all landfills) and the particular facility or activity of concern (e.g., a specific landfill). These factors include:

- design, operation, and maintenance characteristics;
- release characteristics;
- geographic location (pervasiveness and regionality);
- number of sources and amounts of material flowing through or stored in sources; and
- hydrogeology.

Design, operation, and maintenance can influence a source's potential to contribute substances to groundwater through faulty operation and maintenance procedures or through mechanical failure or deterioration; these factors are relatively random. Release characteristics, pervasiveness and regionality, and the number of sources and amounts of material are described in this section. (For general descriptions of sources and details of calculations, see app. A.5.)

Hydrogeology is site-specific, and it influences the potential contribution of individual facilities or activities primarily by affecting the movement of substances into and within groundwater. (See ch. 5 for a discussion of hydrogeologic factors and investigative techniques.)

Release Characteristics

Potential sources of groundwater contamination are highly variable in the spatial (areal) pattern of their releases (table 7). These releases can be: 1) *discrete* releases, where substances emanate from a single identifiable unit; 2) *diffuse* releases over a large area, so that substances cannot be traced to a single identifiable source; or 3) *frontal* or boundary releases, which may or may not emanate

Table 6.—Sources and Classes of Associated Substances[a]

	Organic chemicals				Inorganic chemicals			Biologicals	Radionuclides
	Aromatic hydrocarbons	Oxygenated hydrocarbons	Hydrocarbons **with specific** elements	Other hydrocarbons	Metals/ cations	Nonmetals/ anions	Inorganic acids		
Category I									
Subsurface percolation	■	■	■	■	■	■		■	
Injection wells	□	□	■	□	■	■		■	■
Land application[b]									
a. Wastewater				■	■	■		■	
b. Wastewater byproducts				■	■	■		■	■
c. Hazardous waste	■		■		□	□			
Category II									
Landfills	■	■	■	■	■	■	■	□	■
Open dumps	■	■	■	■	■	■	■	■	
Residential disposal	■	■	■	■	■	■	■	■	
Surface impoundments	■	■	■	■	■	■	■	■	■
Waste tailings					■	■	■		■
Waste piles					■	■	■		■
Materials stockpiles					□	□			
Graveyards					■	■		■	
Animal burial					□	□		□	
Above-ground storage tanks	□	□	□	■	□	□	□	□	□
Underground storage tanks	■	■	■	■	■	□	□	□	□
Containers	□	□	□	□	□	□	□	□	□
Open burning and detonation sites					□	□			
Radioactive disposal sites									■
Category III									
Pipelines	□	□	□	■	□	□	□	□	
Materials transport and transfer operations	□	■	■	■	□	□	□	□	□
Category IV									
Irrigation practices					■	■			
Pesticide applications			■						
Fertilizer applications			■		■	■		□	
Animal feeding operations					■	■		□	
De-icing salts applications					□	■			
Urban runoff	□	□	■	□	■	■	□	■	
Percolation of atmospheric pollutants					■	■			
Mining and mine drainage					■	■	■		■

Key:

■ Contaminant in class has been found in groundwater associated with source.

□ Potential exists for contaminant in class to be found in groundwater associated with source.

Table 6.—Sources and Classes of Associated Substances—Continued

	Organic chemicals				Inorganic chemicals			Biologicals	Radionuclides
	Aromatic hydrocarbons	Oxygenated hydrocarbons	Hydrocarbons with specific elements	Other hydrocarbons	Metals/ cations	Nonmetals/ anions	Inorganic acids		
Category V									
Production wells									
a. Oil	◁			◀	◀	◀			
b. Geothermal and heat recovery					◀	◀			◁
c. Water supply					◀	◀			
Other wells	◁	◁	◁	◁	◁	◁	◁	◁	◁
Construction excavation					◁	◁			
Category VI									
Groundwater-surface water interactions	◁	◁	◁	◁	◁	◁	◁	◁	◁
Natural leaching					◀	◀			◀
Salt-water intrusion					◀	◀			◀

[a] Based primarily on University of Oklahoma, 1983. Additional information from Colton, et. al., 1979; Metropolitan Area Planning Council, 1982; Ridgley, et. al., 1982; San Francisco Bay Regional Water Quality Control Board, 1983; and Kaplan, et. al., 1983.

[b] Documentation was not available on the land application of non-hazardous wastes.

SOURCE: Office of Technology Assessment.

from a single source but which generally impact groundwater along a front or boundary.

The first pattern, discrete releases, is typical of point sources; diffuse and frontal release describe non-point sources. But there are exceptions. For example, point sources may be so densely situated (e.g., oil production fields) that substances are released in an essentially diffuse pattern, and no single source can be identified. If numerous different types of point sources are located in an area (e.g., urban area), the specific source of the substances found in groundwater may also be obscured. For these reasons, the categorization of a source according to spatial release patterns is often site-specific and thus not rigid.

Sources also vary in the temporal pattern of potential releases (table 7). Some sources that are active year-round are influenced by seasonal patterns of rainfall and recharge (e.g., subsurface percolation, materials stockpile runoff, and natural leaching). Other year-round sources are not affected by the elements because their associated materials are enclosed or otherwise protected from climate (e.g., storage tanks and containers); in these cases, releases are random with respect to season. Some sources are active only at certain times of the year (e.g., agricultural activities and de-icing salts applications).

The age of an individual facility may also influence temporal release patterns. For example, more concentrated levels of substances may be released during the active years of a facility's operations, or if there is increasing mechanical failure or deterioration over time. Salinity from irrigation flow (a Category IV source, which is seasonal in intensity) may also be age-dependent in salts built up in the soil over time.

Geographic Location: Pervasiveness and Regionality

Sources of groundwater contamination are either widespread throughout the Nation, located in a few concentrated areas or regions, or extremely localized (table 7). The majority of widespread sources are point sources; they are numerous but also tend to be concentrated in heavily populated areas. Most point sources are Category II sources and are waste-related (e.g., landfills and surface impoundments). Some non-waste point sources (e.g., storage tanks and water supply wells) and, importantly, some non-point sources (e.g., pesticide applications and

Table 7.—Summary of Source Characteristics[a]

	Individual facility/activity			Aggregate of facilities/activities			
	Purpose[a]	Spatial release pattern[b]	Temporal release pattern[c]	Pervasiveness[d]	Diversity of known contaminants[e]	Numbers[f]	Amounts of material[g]
Category I							
Subsurface percolation	W	P[h]	Y[i]	R	High	High	High
Injection wells	W/NW	P	Y[i],S	R	Moderate	High	High
Land application	W	D,P	S	R	Moderate	Moderate	Low
Category II							
Landfills	W	P[h]	S[i]	W	High	High	Moderate (High?)
Open dumps	W	P[h]	S[i]	W	High	Moderate	Moderate
Residential disposal	W	P[h]	S[i]	W	High	?	?
Surface impoundments	W	P[h]	S[i]	W	High	High	High
Waste tailings	W	P[h]	S[i]	R	Moderate	?	High
Waste piles	W	P[h]	S[i]	R	Moderate	?	High
Materials stockpiles	NW	P[h]	S[i]	W	Low	?	High
Graveyards	W	P[h]	S[i]	W	Moderate	?	?
Animal burial	W	P[h]	S[i]	L	Low	?	?
Aboveground storage tanks	W/NW	P[h]	R	W	Low	?	?
Underground storage tanks	W/NW	P[h]	R	W	Moderate	High	Moderate
Containers	W/NW	P[h]	R	W	Low	Moderate (?)	Moderate
Open burning and detonation sites	W	P	S	L	Low	Low (?)	Low
Radioactive disposal sites	W	P	Y,S,R,[i]	L	Low	Low	Low
Category III							
Pipelines	W/NW	P[h],F	R	W	Low	Moderate	High
Materials transport and transfer operations	W/NW	P[h],F	R	W	Moderate	Moderate	Moderate
Category IV							
Irrigation practices	NW	D	S[i]	R	Low	Moderate	Moderate
Pesticide applications	NW	D	S[i]	W,R	Low	High	Low
Fertilizer applications	NW	D	S	W,R	Moderate	High	Moderate
Animal feeding operations	W	P[h]	Y	W	Low	Moderate	Low
De-icing salts applications	NW	F	S	R	Low	?	Moderate
Urban runoff	W	P,D,F	S	W	Moderate	Moderate	?
Percolation of atmospheric pollutants	W	D	S	W	Low	?	?
Mining and mine drainage	W	P,D,F	S[i]	R	Moderate	High	Low (?)
Category V							
Production wells	NW	P	Y[i]	R	Moderate	High	Moderate
Other wells	NW	P	Y[i]	W	Low	?	?
Construction excavation	W	P,D,F	S	W	Low	?	Moderate
Category VI							
Groundwater-surface water interactions	W	F	S	W	Low	NA	?
Natural leaching	NW	D,F	Y,S	L	Moderate	NA	?
Salt-water intrusion	NW	D,F	S	R	Moderate	NA	?

[a] Purpose: W = waste; NW = non-waste.
[b] Spatial Release Pattern: P = point; D = diffuse; F = frontal.
[c] Temporal Release Pattern: Y = year-round; S = seasonal; R = random.
[d] Pervasiveness: W = widespread; R = regional; L = local.
[e] Diversity of known contaminants (based upon Table 1.4): Low = 1-2 associated classes; Moderate = 3-5 associated classes; High = 6-8 associated classes.
[f] Number (based upon Table 1.6): Low = < 1,000 facilities; Moderate = 1,000-25,000 facilities, 10-20,000 spills, 100,000-1,000,000 miles, or 10-100 million acres; High = 725,000 facilities or > 100 million acres; ? = unable to obtain sufficient information; NA = not applicable.
[g] Amounts (based upon Table 1.6): Low = < 10 billion gallons, < 10 million tons, < 10 million cubic yards, < 1 billion barrels, or < 100 million acres; Moderate = 10-250 billion gallons, 10-250 million tons, 10-100 million cubic yards, 1-10 billion barrels, or 10-250 million acres; High = > 250 billion gallons, > 250 million tons, or > 10 billion barrels; ? = unable to obtain sufficient information.
[h] Point sources, but typical dense concentration leads to a diffuse problem (individual sources are not traceable).
[i] Release characteristics are also a function of age.

SOURCE: Office of Technology Assessment.

urban runoff) are also widespread. But widespread point sources may be of greater concern in some regions than in others because of variations in hydrogeology or the level of dependence on groundwater.

Regional sources tend to be associated with heavily populated areas or major economic activities; often they are numerous or have large amounts of material associated with them. They include sources in Categories I, II, V, and VI. For example, septic tanks are relatively more concentrated in California and the Northeast, fertilizers and pesticides are applied primarily in the West and Midwest, brine disposal wells are located primarily in the Southwest, and mine drainage is found mostly in the East, Midwest, and Southwest. A regional source such as salt-water intrusion is naturally limited to certain coastal areas. In addition, because the distribution of sources is dynamic (e.g., industrialization is increasing in the South, and energy development is increasing in Appalachia and in the Midwest), sources related to previous land uses, rather than present-day activities, may be responsible for the contamination.

The regional nature of some activities does not preclude their associated substances from becoming widespread. For example, only a few manufacturers are primary producers of the active ingredients in pesticides, but their products are used by intermediate manufacturers, small industries, residential households, and agricultural operations throughout the country.

Maps could be used to show the predominance of sources on a regional scale as well as the pervasiveness of sources nationwide. Maps are not included in this report for two major reasons:

1. Available maps generally refer to one source or to several related sources. Because the information contained on different maps involves different assumptions and levels of detail, the relative importance of different sources is difficult to ascertain.
2. Most importantly, site-specific conditions (including hydrogeology), which are essential for any conclusions or predictions about groundwater contamination, are not included on these maps. Relationships would need to be established between source locations and hydrogeologic areas most vulnerable to the entrance and subsequent movement of substances in groundwater and source locations.

Numbers of Sources and Amounts of Material Flowing Through or Stored in Sources

Current estimates of the number of sources and the amounts of materials flowing through or stored in these sources are presented in table 8. As can be seen, many of the estimates in the 1977 Report to Congress (EPA, 1977; Miller, 1980) are updated, and initial estimates for many additional sources have been developed in OTA's analysis. Details of the calculations are in appendix A.5.

At least four limitations are inherent in these estimates:

1. The estimates are specifically for the amounts of material flowing through or stored in the source and are **not** estimates of the amounts of material actually reaching the groundwater (unless otherwise indicated). Thus the estimates suggest only the maximum potential for groundwater contamination.
2. An estimate of the amount reveals nothing about the nature and concentration of substances in that material. Industrial and municipal sludge provides an example. The amount of industrial sludge used in land applications is roughly 7 percent of that used from municipal systems, yet often the chemical compounds or their concentrations in industrial sludge (e.g., inorganic acids and higher concentrations of hydrocarbons) pose greater health threats than the chemical compounds found in municipal sludge.
3. Accuracy of the quantitative estimates varies considerably from source to source, depending on the underlying assumptions and completeness of the data. This study has attempted to address this problem by indicating the range of values within which the true value probably falls (see app. A.5 for details), but even this approach is arbitrary. **It is important to remember that there is a high degree of uncertainty underlying the estimates and that**

Table 8.—Numbers of Sources and Amounts of Material Flowing Through or Stored in Sources[a]

	OTA Update			1977 Report	
Source	Approximate number of facilities	Approximate amount of material[b]	Possible uncertainty in number estimate[c]	Possible uncertainty in amount estimate[c]	Approximate amount of material
Category I					
Subsurface percolation					
Domestic	16.6-19.5 million	820-1,460 bgy	< 2 ×	< 2 ×	800 bgy
Industrial	25,000	1-2 bgy	> 10 ×	> 10 ×	1.2 bgy
Injection wells					
Hazardous waste	87	8.6 bgy[d]	< 10 ×	< 10 ×	—
Drainage, etc.	350,000	?	< 10 ×	?	—
Brine	140,000	525 bgy	< 10 ×	< 10 ×	460 bgy
Non-waste (enhanced oil recovery)		24.5 bgy	?	< 10 ×	—
Non-waste (solution, in-situ)	12,000	?	?	< 10 ×	0.3 mt
Land application					
Municipal sludge	2,500	3-4 mty (dry)	< 10 ×	< 10 ×	4 mty
Industrial hazardous waste	70	0.10 bgy[d]	< 10 ×	< 10 ×	—
Spray irrigation	485	?	> 10 ×	?	—
Category II					
Landfills					
Industrial hazardous waste	199	0.81 bgy[d]	< 10 ×	> 10 ×	50 bgy
Industrial non-hazardous waste	75,700	40-140 mty (wet)	< 10 ×	> 10 ×	
Utility	?	30 mty (wet)	?	> 10 ×	—
Municipal	15-20,000	138 mty	< 2 ×	< 2 ×	90 bgy
Open dumps	2,400	10 bgy	> 10 ×	> 10 ×	—
Residential disposal sites	?	?	?	?	—
Surface impoundments					
Hazardous waste	1,078	35.8 bgy[d]	< 10 ×	< 10 ×	—
Non-hazardous waste	180,000	1,800 bgy[e]	< 2 ×	< 10 ×	161 bgy
Waste tailings	?	580 mty	?	< 2 ×	—
Waste piles					
Hazardous waste	174	0.4 bgy	> 10 ×	> 10 ×	—
Non-hazardous waste	?	1,730 mty	?	< 2 ×	—
Materials stockpiles	?	700 mty	?	< 10 ×	—
Graveyards	?	?	?	?	—
Animal burial	?	?	?	?	—
Aboveground storage tanks	?	?	?	?	—
Underground storage tanks					
Hazardous waste	2,031	13.8 bgy	< 10 ×	< 10 ×	—
Non-hazardous waste	2.5 million	25 bg	< 2 ×	< 10 ×	—
Non-waste	?	?	?	?	—
Containers					
Hazardous waste	3,577	0.16 bgy[d]	> 10 ×	> 10 ×	—
Non-hazardous waste	?	?	?	?	—
Non-waste	?	?	?	?	—
Open burning and detonation sites	?	?	?	?	—
Radioactive disposal sites	31[f]	3.7 million cubic yards	< 2 ×	< 2 ×	—
Category III					
Pipelines					
Hazardous waste	?	?	?	?	—
Non-hazardous waste	700,000 miles	280 bgy[e]	< 10 ×	> 10 ×	250 bgy

Table 8.—Numbers of Sources and Amounts of Material Flowing Through or Stored in Sources[a]—continued

	OTA Update			1977 Report	
Source	Approximate number of facilities	Approximate amount of material[b]	Possible uncertainty in number estimate[c]	Possible uncertainty in amount estimate[c]	Approximate amount of material
Category III—continued					
Non-waste	175,000 miles	10 billion barrels	?	?	—
Materials transport and transfer operations					
Hazardous waste	16,000 spills	14 mty	<10×	>10×	—
Non-hazardous waste					
Non-waste	?	?	?	?	—
Category IV					
Irrigation practices	50-60 million acres	169 million acre-feet	<2×	<2×	—
Pesticide applications	280 million acre-treatments	0.26 mty active ingredients	<2×	<2×	—
Fertilizer applications	229 million acre-treatments	42 mty	<2×	<2×	—
Animal feeding operations	1,935	8 mty	<2×	<10×	—
De-icing salts applications	?	10-12 mty	?	<2×	—
Urban runoff	21.2-32.6 million acres	?	<2×	?	—
Percolation of atmospheric pollutants	NA	?	?	?	—
Mining and mine drainage					
Surface	15,000 active	4 million acres; 0.36-1.0 mty acid	<10×	<10×	108 billion gallons
Underground	67,000 inactive				
Category V					
Production wells					
Oil wells	548,000 activity 2 million abandoned	[g]	<10×	<10×	—
Geothermal, heat recovery	32	?	?	?	—
Water supply	350,000	?	?	?	—
Other wells (non-waste)					
Monitoring	?	?	?	?	—
Exploration	?	?	?	?	—
Construction excavation	?	45 mty	?	>10×	—
Category VI					
Groundwater-surface water interactions	NA	?	NA	?	—
Natural leaching	NA	?	NA	?	—
Salt-water intrusion	NA	?	NA	?	—

[a] ? = OTA unable to obtain sufficient information to develop estimate.
— = No estimate presented in 1977 report (EPA, 1977).
NA = Not applicable.

[b] mty = million tons per year.
bgy = billion gallons per year.
bg = billion gallons.

[c] Confidence in estimates is defined as follows (see app. A.5 for more details):
<2x = estimate considered correct within 100%.
<10× = estimate considered correct within one order of magnitude.
>10× = estimate *could* be incorrect by more than one order of magnitude.

[d] Note that this figure refers to hazardous wastes regulated under RCRA (see app. A.5).

[e] Estimate of actual amount of leachate.

[f] Excludes nuclear reactors.

[g] See estimate for brine injection (app. A.5).

SOURCE: Office of Technology Assessment.

they are best used to indicate the most numerous and most material-intensive sources.

4. Comparing estimates is difficult because they are expressed in different units of measurement. The units cannot be converted into a common base unit; thus only simple categorizations of large versus small numbers or amounts can be made. (See the section on *Identifying Sources With "Significant" Potential To Contribute Substances to Groundwater,* where this problem is encountered again, for more details.)

Given these caveats, table 8 is still useful in at least two ways:

1. It indicates sources which are numerous and/or have large amounts of associated materials.
2. Table 8 shows that **non-point sources (e.g., Category IV, including fertilizer and pesticide applications) and sources dealing with non-waste products (e.g., Category II, including underground storage tanks) and with non-hazardous wastes (e.g., Category I, including brine disposal wells) are often as important—in terms of numbers or amounts of material as defined in table 7—as point sources or hazardous waste sources.** Many of the non-point sources have associated with them chemicals that are highly toxic (e.g., pesticide applications) or very diverse (e.g., underground storage tanks); see the previous section on *Association of Substances Found in Groundwater With Sources*).

Quantitative estimates of the numbers of sources are available at least in part for 19 sources. The contribution of some sources to groundwater contamination is difficult to measure (e.g., salt-water intrusion), and data are incomplete for others. Of equal importance, estimates of amounts do not exist for 11 sources and are incomplete for seven others. For some sources, amounts are technically difficult to measure (e.g., drainage wells and residential disposal); for others, local information is available but is difficult to compile on a national level (e.g., non-waste containers and water supply wells). With increased time and effort, investigators can probably improve estimates for some sources (e.g., industrial subsurface percolation and hazardous waste containers) and possibly obtain sufficient information to generate first estimates for some of the sources for which there are no estimates (e.g., spray irrigation).

The most numerous sources include: subsurface percolation (domestic), injection wells (brine disposal and drainage), industrial landfills, surface impoundments, underground storage tanks, pipelines, irrigation practices, pesticide applications, fertilizer applications, mine drainage, and oil wells.

The largest amounts of material apparently flow through or are stored in the following sources: subsurface percolation (domestic), brine disposal wells, industrial and municipal landfills, surface impoundments, waste tailings and piles, materials stockpiles, and pipelines. **Much of the material that enters groundwater comes from non-point sources,** such as applications of pesticides and fertilizers, especially in particular regions of the country. **Non-waste** sources such as injection wells, storage tanks, and many agricultural activities, **and non-hazardous waste, and/or non-waste sources** contribute large amounts of material.

Photo credit: Paula Stone, Office of Technology Assessment

Of an estimated 2.4 million steel underground storage tanks in the United States, as many as one-fourth may be used by farmers; other important users include service stations (using an estimated 50 percent) and government agencies (using an estimated 5-6 percent) (see app. A.5).

POTENTIAL FOR SOURCES TO CONTRIBUTE SUBSTANCES TO GROUNDWATER

Determining the contribution of any source to groundwater contamination depends on understanding a broad range of technical, economic, and social factors. Economic and social factors affect where sources are located, how they are used, and what they are used for. The actual contribution of substances by any source will depend on such technical factors as biodegradation rates, surface and subsurface hydrology (e.g., percolation and adsorption rates), the amount and type of wastes, release patterns, number of sources, and source characteristics (condition, maintenance, and operation procedures).

Two basic approaches are discussed below for identifying which sources have the potential for contributing significant amounts of substances to groundwater. One approach involves the use of physical and mathematical models to predict when and which sources release substances to groundwater and what happens to the substances once they enter groundwater. This approach can also involve record-keeping at individual facilities. In the second approach, descriptive criteria are developed in order to generate lists of important sources (as defined on the basis of those criteria).

Modeling the Potential of Sources To Contaminate Groundwater

Efforts to protect groundwater would be aided by a priori information on when an individual facility or activity will release substances with the potential to enter groundwater, and by estimates of what portion of these substances will actually enter groundwater.

Little work has been done to develop measures of the potential for **sources** to contribute substances to groundwater. In general, the site-specific nature of hydrogeology and the varying characteristics of individual sources have precluded development of predictive models. One existing model for steel underground storage tanks uses tank age and local soil condition data to generate predictions about the situations in which tanks will develop leaks (Rogers, no date). If an inventory of underground storage tanks (including specific age data) were available, at-risk situations identified by the model could be investigated. Apparently this type of modeling has not been developed for other sources and is limited by data availability.

Physical and mathematical models are available that predict the behavior and movement of substances once they enter groundwater. (See app. A.5 for references.) Most of the models yield a temporally varying description of the spatial distribution of a substance in an aquifer (see ch. 5). Input requirements generally relate to underlying soils and other hydrogeologic features and the amount or rate at which the aquifer is receiving the substance. If existing contamination and aquifer characteristics are known, some models can be run in reverse to determine the amount of the substance that must have been released from its source to produce the given conditions. These models rely on empirical measurements for input; the value of their output, therefore, is highly dependent on both the underlying assumptions and the quality of the input data.

Measuring contamination potential thus also involves record-keeping at individual facilities. Losses caused by leakage or infiltration of leachate can be estimated via water balance, injected waste leakage, or back-calculation procedures (University of Oklahoma, 1983). However, these procedures are basically empirical or bookkeeping for an individual facility, and the information gained is used to estimate leachate generation or the amount of contaminated recharge at that particular facility. Applicability of these prediction methods to other similar facilities is limited. Historic flow records could contribute to crude predictions, but the records are generally not available.

Identifying Sources With "Significant" Potential To Contribute Substances to Groundwater

OTA's analysis attempted to develop objective criteria that could be used to identify and list important sources, i.e., sources with a "significant" potential to contaminate groundwater. **However, in the course of developing these lists, a number of problems became apparent that severely limited the usefulness of the lists.**

Developing a single unambiguous set of objective criteria is not a simple task. One investigator might believe that amounts of material are a sufficient indicator of "importance," and others might be concerned with the diversity of substances associated with various sources. Groups of criteria might be used, **but the lists of important sources will differ depending on which sets of criteria are selected,** as shown below.

An additional problem concerns comparisons of different units of measurement for a single criterion. For example, suppose that the amount of material handled by a source is the criterion under consideration. In table 7, amounts of material are measured in gallons, tons, cubic yards, barrels, acres, and acre-feet. **Definition of a "large" versus "small" amount is arbitrary because of the inability to make comparisons among different units of measurement.** In addition, documentation or estimation of large amounts of material (using any definition of large) does not necessarily mean that large amounts of substances will be released into the groundwater; estimates of large amounts should be viewed only as upper bound indicators of the potential for contaminant release.

To illustrate some of the above problems and to indicate the context in which such lists could be used, listing is examined in detail. As an example, one set of criteria was selected, comprised of four characteristics described in the section on *Factors Influencing a Source's Potential To Contaminate Groundwater*: number, amounts of material, diversity of substances, and pervasiveness. Although these criteria might seem to be relatively objective, all entail arbitrary definitions of low (or small), moderate, and high (or large), The definitions thus determine the evaluations made in any list.

Information is even more subjective or sparse for other possible criteria, such as the degree to which source control (of operating and maintenance procedures) is required to prevent the release of substances, the potential of the source to introduce new substances into groundwater, the toxicity of associated substances, and the nature of release characteristics. These criteria are useful in characterizing sources, but they are more difficult to interpret when considering the question of the potential of any particular source to contaminate groundwater. For example, the release of substances with any of the spatial or temporal release patterns discussed above could result in little to significant contamination.

Using the above four criteria, several lists of sources were generated by using different groupings of the criteria and different levels of importance for particular criteria (e.g., use of high numbers in one list, moderate to high numbers in another list). A selection of these lists is presented in table 9. Although some sources fit into many of these lists, a major conclusion is that the exact listing changes as different criteria are selected. For example, if regulatory authorities are interested in groundwater contaminated by a high diversity of substances, there are five important sources (subsurface percolation, landfills, open dumps, residential disposal, and surface impoundments) and, of these, the most important source would be surface impoundments (based on table 6). If the number of facilities alone is important (e.g., as a gauge of regulatory efforts required for control), nine sources are of primary interest and, of these, the most important source would be subsurface percolation (based on table 8).

Among the first nine lists in table 9, seven sources appear on more than one-half the lists: subsurface percolation, injection wells, landfills, open dumps, surface impoundments, underground storage tanks, and fertilizer application. Of all sources, only the surface impoundment source is widespread and has a "high" ranking for the other three criteria (see table 7). Additional criteria could justify the inclusion of specific sources. For example, it is known that a high percentage of underground storage tanks are leaking gasoline and causing a number of contamination incidents (see app. A.5). Location over vulnerable aquifers (e.g., sole-source aquifers) would be another reason for including surface impoundments and other sources on a list.

The first nine lists are based exclusively on the above four criteria, which tend to be quantitative; quantitative criteria will generally bias a list toward

Table 9.—"Important" Sources of Groundwater Contamination Based on Selected Sets of Criteria[a]

Sources/criteria[b]	1 H diversity	2 H amounts	3 H numbers	4 H numbers M-H diversity	5 M-H numbers M-H amounts H diversity	6 M-H numbers M-H amounts M-H diversity Widespread	7 M-H numbers M-H amounts M-H diversity Widespread or Regional	8 Same as 7 but H diversity only	9 Same as 7 but at least one H ranking	10 Toxicity
Subsurface percolation	X	X	X	X	X		X	X	X	X
Injection wells		X	X	X			X		X	X
Land application										X
Landfills	X	X	X	X	X	X	X	X	X	X
Open dumps	X				X	X	X	X	X	X
Residential disposal	X									X
Surface impoundments	X	X	X	X	X	X	X	X	X	X
Waste tailings		X								
Water piles		X								X
Materials stockpiles		X								
Aboveground storage tanks										X
Underground storage tanks			X	X		X	X		X	X
Containers										X
Pipelines		X								X
Materials transport						X	X			X
Pesticides applications			X							X
Fertilizer applications			X	X		X	X		X	
Mining			X	X						
Production wells (oil)			X	X			X		X	

[a] Abbreviations: H = High.
M-H = Moderate to High.

[b] Other sources listed in table 5 do not meet any of the selected criteria.

SOURCE: Office of Technology Assessment.

point sources, because point sources are relatively easy to identify and count or measure (note that of the above seven sources, only fertilizer applications is a non-point source). In contrast, suppose toxicity, a criterion that is more descriptive of the potential health effects of substances and is not biased toward point sources, is selected. Then the list (see the toxicity column in table 9) would include pesticide applications, open dumps, residential disposal (e.g., TCE and other halogenated aliphatic hydrocarbons), open dumps, and the facilities/activities of each source type that deal with hazardous wastes. Although this list does focus on hazardous waste sources, it also includes several non-point sources (pesticide applications, residential disposal, land application, pipelines, and materials transport). Other criteria that could be used in this manner include economic impacts and environmental impacts.

This exercise illustrates the difficulty in identifying one single list of sources that would satisfy all sets of criteria—**the list of sources generated depends on the criteria selected for identifying "important" sources.** In addition, groundwater contamination problems differ from region to region and from site to site, thereby making national lists somewhat tenuous. Listing the sources is not as important as recognizing that materials flow through society; that **problems involve non-point, non-hazardous, and non-waste sources;** that **problems vary from region to region; and that groundwater contamination is highly site-specific.**

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Chapter 3

Federal Institutional Framework To Protect Groundwater From Contamination

CHAPTER OVERVIEW

OTA's assessment of Federal activities regarding groundwater contamination involved examination of 16 Federal statutes and discussions with representatives of 11 Federal agencies. The laws and programs selected for review relate to sources of contamination, the regulation of potential contaminants, and the use of groundwater for drinking water supplies. This chapter provides a summary of the existing Federal laws and programs that protect groundwater quality. In addition, aspects of the laws and programs are analyzed that define or support—and are thus shared in common by—detection, correction, and prevention activities.

The following topics are included:

- relevance of Federal laws to the protection of groundwater;
- summary of Federal laws and programs;
- sources of contamination addressed by Federal laws;
- water quality standards;
- existing mechanisms for interagency coordination with respect to implementation of legislative mandates; and
- efforts of the Federal Government to improve its own capabilities and those of the States to protect groundwater.

Federal detection, correction, and prevention activities are discussed in greater detail in chapters 6, 9, and 11, respectively.

The general conclusions drawn from this information follow.

There is no explicit, comprehensive national legislative mandate to protect groundwater from contamination. Federal laws and programs do not address all sources known to contaminate groundwater, the vast majority of substances that have already been found or have the potential to be found in groundwater, or all uses of groundwater.

Specifically with respect to *sources,* different Federal laws and programs address different sources of groundwater contamination in different ways. The differences often have little relation to the potential for a source to cause contamination. In general, more stringent requirements are applied to selected point sources (especially those associated with hazardous wastes), rather than non-hazardous waste, non-waste, and non-point sources.

The Federal approach to *contaminants,* in terms of standards, is neither complete nor consistent. (The Federal regulation of potential contaminants for prevention is discussed in ch. 11.) Although drinking is the principal *use* addressed by Federal statutes, not all drinking water supplies are covered (see ch. 6).

There are many Federal laws and programs directed toward assisting the States and Federal agencies with groundwater contamination problems. These generally provide for financial and technical assistance and research and development. Several laws also authorize the States to implement federally mandated programs and establish minimum requirements for such programs. However, Federal efforts to protect groundwater quality are fragmented, and there is no single agency or organization responsible for *all* groundwater programs and activities; several coordination mechanisms are used.

RELEVANCE OF FEDERAL STATUTES TO GROUNDWATER PROTECTION

Protection of groundwater is not covered comprehensively by any one Federal law; nor is one Federal agency or office responsible for overseeing or coordinating all groundwater programs and activities.[1] Although the groundwater protection strategy of the U.S. Environmental Protection Agency acknowledges the need for comprehensive resource management, the details of the strategy do not fully provide for it (EPA, 1984).[2]

OTA's analysis has identified 16 principal pieces of Federal legislation that authorize numerous programs and activities relevant to groundwater protection, and it develops a framework for determining how current laws and programs contribute to the detection, correction, and prevention of contamination. Groundwater protection per se is *not,* however, the primary objective of any of the statutes.

Table 10 summarizes the relationship between Federal legislation and groundwater protection activities including: detection/investigatory activities; corrective actions for contaminated groundwater; measures to prevent contamination; and standards for contaminants used in detection, correction, and prevention activities. Although table 10 presents an extensive array of programs and activities, **Federal efforts overall are not fully protecting groundwater resources.** For example, not all sources of groundwater contamination are included, and for the general source types that are, not all related facilities and/or activities may be covered; not all drinking water supplies are monitored routinely; and standards have not been developed for most contaminants that have already been detected in groundwater.

SUMMARY OF FEDERAL STATUTES AND PROGRAMS

Table 11 summarizes the objectives and major provisions of the statutes examined in this study, lists the Federal agencies responsible for their implementation, and indicates the relationship between the Federal laws and the States. (State programs are discussed in chs. 4, 7, 10, and 12.) Additional Federal activities undertaken to support or comply with these laws are summarized in table 12. Note that Federal statutes have not been ranked in terms of their relative importance to groundwater protection for many of the same reasons that sources were not prioritized in chapter 2—i.e., "importance" depends on the ranking criteria chosen and site conditions.

Federal Legislation Passed Prior to the 1970s

Early Federal legislation regarding water quality in the United States focused primarily on surface waters. These statutes were the precursors of the more comprehensive water quality legislation passed in the 1970s.

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[1] The EPA Office of Ground-Water Protection, established on Apr. 2, 1984, will be responsible for coordinating all *EPA* groundwater activities. The office will also "work with other Federal agencies . . . (and) convene an Interagency Committee on Ground Water . . . Other committees will be established as needed" (EPA, 1984).

[2] For example, the strategy depends on the *voluntary* participation of the States with financial assistance coming from *existing* grant programs and supporting program *development*. Existing grant programs are not deemed adequate by the States and funding is also required for program implementation, as discussed in chs. 4,7,10, and 12.

The strategy also singles out *three* inadequately addressed sources—underground gasoline storage tanks, surface impoundments, and landfills—for action, which is to emphasize *study* and *review* and, in addition for underground storage tanks, a Chemical Advisory and voluntary steps. Information about 33 sources (including these three) is presented in ch. 2 and app. A and analyzed throughout this report.

Further, the strategy states that current and potential drinking water supplies and water having other beneficial uses (Class II), which are the majority of usable groundwater in the United States, will receive levels of protection consistent with EPA's *existing* regulations. The adequacy of existing regulations is analyzed in ch. 3,6,9, and 11.

For a discussion of the history and a comparison of EPA's efforts to develop a groundwater strategy (EPA, 1980, 1983), see Feliciano, 1984.

Table 10.—Summary of Federal Programs and Activities Related to the Protection of Groundwater Quality

Statutes	Investigations/detection				Correction		Prevention				
	Inventories of sources[a]	Ambient groundwater monitoring	Groundwater monitoring related to sources[a]	Water supply monitoring	Federally funded remedial actions	Regulatory requirements for sources[a]	Regulate chemical production	Standards for new/existing sources[a]	Aquifer protection	Standards	Other[b]
Atomic Energy Act			X		X	X		X		X	
Clean Water Act	X	X	X		X			X		X	X
Coastal Zone Management Act											X
Comprehensive Environmental Response, Compensation, and Liability Act	X		X		X						
Federal Insecticide, Fungicide, and Rodenticide Act			X				X	X			
Federal Land Policy and Management Act (and associated mining laws)			X					X			
Hazardous Liquid Pipeline Safety Act	X							X			
Hazardous Materials Transportation Act	X							X			
National Environmental Policy Act											X
Reclamation Act					X						
Resource Conservation and Recovery Act	X		X			X		X			
Safe Drinking Water Act	X		X					X	X	X	
Surface Mining Control and Reclamation Act			X		X			X			
Toxic Substances Control Act			X				X	X			
Uranium Mill Tailings Radiation Control Act			X		X	X		X			
Water Research and Development Act											X

[a] Programs and activities under this heading relate directly to specific sources of groundwater contamination. Table 13 summarizes the sources addressed by the statutes.

[b] This category includes activities such as research and development and grants to the States to develop groundwater-related programs.

SOURCE: Office of Technology Assessment.

Table 11.—Descriptions of Major Federal Statutes Relevant to the Protection of Groundwater Quality

Statute	Objectives and provisions relevant to groundwater protection	Responsible Federal agencies	Relationship to the States
Atomic Energy Act of 1954, 42 U.S.C. 2011[a]	One purpose of the act is to encourage the development and use of atomic energy for peaceful purposes consistent with the common defense and security and the health and safety of the public. The act authorizes the regulation of the development and utilization of atomic energy, including the storage and disposal of radioactive wastes.	Department of Energy Nuclear Regulatory Commission Environmental Protection Agency—Office of Radiation Programs	Regulation of certain radioactive materials is delegated by NRC to the States that participate in the Agreement States Program. Pursuant to the Low-Level Radioactive Waste Policy Act of 1980, States are currently engaged in regional and individual planning efforts to site new disposal facilities.
Clean Water Act of 1977, 33 U.S.C. 1251-1378[b]	The objective of the statute is to restore and maintain the physical, chemical, and biological integrity of the Nation's waters. Activities authorized by the act include: — the construction of sewage treatment works and the use of alternative waste management techniques (Section 201); — the establishment of effluent standards and the regulation of point discharges of pollutants (Sections 302, 306, 307, and 402); — the development of ambient water quality criteria (Section 304); — regulation of the disposal of dredged or fill materials (Section 404); — establishment of State or regional water quality management plans, and the establishment of a program to develop Best Management Practices to control non-point source pollution in rural areas (Section 208); — responses to oil discharges into navigable water (Section 311).	Environmental Protection Agency—Office of Water Programs Operations, Office of Water Regulations and Standards, and Office of Water Enforcement and Permits Department of Agriculture—Soil Conservation Service and Agricultural Stabilization and Conservation Service (Section 208) Department of Transportation—U.S. Coast Guard (Section 311)	States (or local planning agencies) were required by Section 208 to submit areawide water quality management plans to EPA that identified and proposed solutions to water quality problems (including point and non-point sources affecting surface water and groundwater). Funding for Section 208 activities was terminated in 1981. Grants under Sections 106 and 205(j) are now being used to support planning activities. State (or interstate agency) grants are authorized (Section 106) to assist with the administration of water pollution control activities required by the act. Funds are also available from Sections 205(g) and (j) which are reserves from State construction grant allotments. While Section 205(g) funds are used primarily to support construction grant programs (for sewage treatment works), Section 205(j) funds are authorized to support State water quality management planning. Regulatory authority for Section 402 is delegated to States for the point discharges of pollutants into navigable waters.[c] Section 303 requires States to adopt water quality effluent standards for such discharges consistent with Federal standards.
Coastal Zone Management Act of 1976, 16 U.S.C. 1451	One policy specified in the statute is to preserve, protect, develop, and where possible, restore or enhance the resources of the Nation's coastal zone for this and succeeding generations. The act authorizes funding to encourage and assist the States in the development and	Department of Commerce—National Oceanic and Atmospheric Administration	States are eligible to receive grants if a coastal zone management program is developed that meets minimum Federal requirements.

Table 11.—Descriptions of Major Federal Statutes Relevant to the Protection of Groundwater Quality—continued

Statute	Objectives and provisions relevant to groundwater protection	Responsible Federal agencies	Relationship to the States
	implementation of management programs with respect to the use of land and water resources in the coastal zone, including efforts to mitigate salt-water intrusion.		
Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601	The statute does not contain an explicit policy statement. The act authorizes the Federal Government to respond whenever there is a release or threat of release of hazardous substances, pollutants, or contaminants into the environment which may present an imminent and substantial danger to public health or welfare. Responses are financed by excise taxes levied on petroleum and chemical feedstocks. The act also establishes liability for the cost of response actions on responsible parties and provides for compensation of expenses incurred by the government.[d]	Environmental Protection Agency—Office of Emergency and Remedial Response Department of Transportation — U.S. Coast Guard Department of the Interior	States may enter into a Cooperative Agreement with EPA and assume lead responsibility for remedial actions, or States may enter into a contract with EPA whereby EPA assumes lead responsibility. In either case, States are required to assure payment of 10 percent of the costs (or 50 percent if the site is publicly owned), assume responsibility for all future operation and maintenance required at the site, and assure the availability of an authorized hazardous waste disposal facility if necessary for the disposal of wastes removed during remedial activities.
Federal Insecticide, Fungicide, and Rodenticide Act, as amended 7 U.S.C. 136[e]	The statute does not contain an explicit policy statement. The act requires the registration of all pesticides based on the submission of specified data (Section 3), the classification of pesticides for general or restricted uses (Section 3), and suspension and cancellation of pesticides causing unreasonable adverse effects on the environment (includes water, air, land, plants, man and other animals, and their interrelationships) (Section 6). The act also requires the establishment of procedures for the storage and disposal of pesticide containers and excess pesticides (Section 19), as well as formulation of a National Monitoring Plan for pesticides (Section 20).	Environmental Protection Agency—Office of Pesticide Programs	Authority is delegated to States for enforcement of FIFRA provisions (e.g., ensuring that pesticides are used in compliance with any Federal restrictions) if States adopt and implement adequate pesticide laws, regulations, and enforcement procedures.[f] States may also assume responsibility for the training and certification of pesticide applicators if Federal approval of a plan for such activities is obtained. Federal funding of State programs is available to those States that enter into cooperative agreements with EPA.
Federal Land Policy and Management Act of 1976, 43 U.S.C. 1701, and associated mining laws.[g]	The statute specifies that it is the policy of the United States that public lands be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values. The act authorizes the regulation of the use of public lands, including mining operations.	Department of the Interior—Bureau of Land Management	Mining regulations may not preempt State laws and regulations regarding the conduct of mining operations or reclamation on Federal lands. States may enter into agreements with BLM to provide for joint administration and enforcement of regulatory programs

Table 11.—Descriptions of Major Federal Statutes Relevant to the Protection of Groundwater Quality—continued

Statute	Objectives and provisions relevant to groundwater protection	Responsible Federal agencies	Relationship to the States
Hazardous Liquid Pipeline Safety Act of 1979, 49 U.S.C. 2001	The statute does not contain an explicit policy statement. The act requires the establishment of Federal regulations for the movement of hazardous liquids by pipeline (and their storage incidental to such movement) and pipeline facilities in or affecting interstate or foreign commerce; such regulations must consider the extent to which they contribute to public safety.	Department of Transportation—Office of Pipeline Safety Regulation	Federal regulations do not apply to intrastate pipelines and associated facilities for which there are applicable State regulations, provided that the State agency is certified annually by DOT.
Hazardous Materials Transportation Act of 1974, 49 U.S.C. 1801[h]	The policy underlying the statute is to protect the Nation adequately against the risks to life and property which are inherent in the transportation of hazardous materials in commerce. The act requires the establishment of Federal regulations for the transportation of hazardous materials (including hazardous wastes) in commerce.	Department of Transportation—Office of Hazardous Materials Regulation	State regulations that are inconsistent with Federal requirements are preempted. Although there is not a formal delegation of authority, States may enter into cooperative agreements with DOT to obtain technical and financial assistance. States may also establish requirements for certain activities not addressed by Federal regulations (e.g., routing the transport of hazardous materials).
National Environmental Policy Act of 1969, 42 U.S.C. 4371	The purposes of the statute include: the declaration of a national policy to encourage productive and enjoyable harmony between people and the environment, and the promotion of efforts to prevent or eliminate damage to the environment and biosphere and to stimulate human health and welfare. The act directs Federal agencies to utilize a systematic, interdisciplinary approach in planning and decisionmaking that may have an impact on the environment and to prepare environmental impact statements for major Federal actions significantly affecting the quality of the human environment.	All Federal agencies[i]	States have opportunity to review and comment on Federal actions under this and other programs under intergovernmental review provisions authorized by Executive Order 12372.
Reclamation Act of 1902, 43 U.S.C. 390(b)	The policy underlying the statute supports the participation and cooperation of the Federal Government with States and local interests in developing water supplies for domestic, municipal, industrial, and other purposes. Some projects funded under the act are for the development of underground water supplies that are contaminated due to natural leaching (e.g., high salt concentrations) or human activities and thus require treatment prior to use.	Department of the Interior—Bureau of Reclamation	Water rights for reclamation projects must be obtained through States' water rights systems. States are involved in project planning activities.

Table 11.—Descriptions of Major Federal Statutes Relevant to the Protection of Groundwater Quality—continued

Statute	Objectives and provisions relevant to groundwater protection	Responsible Federal agencies	Relationship to the States
Resource Conservation and Recovery Act of 1976, 42 U.S.C. 690	The objective of the statute is to promote the protection of health and the environment and to conserve valuable material and energy resources. Subtitle C of the act requires the establishment of regulations for hazardous waste generators, transporters, and owners or operators of facilities who treat, store, or dispose of such wastes. Subtitle D requires the establishment of Federal guidelines for State solid waste management plans.	Environmental Protection Agency—Office of Solid Waste	Regulatory authority for Subtitle C is delegated to States that establish programs that incorporate minimum Federal requirements. Programs may be more stringent than Federal requirements. Financial assistance is authorized to the States for development and implementation of such programs. Although Subtitle D of the act does not mandate the development of State solid waste plans, States are required to meet certain minimum requirements to obtain EPA approval and qualify for Federal financial assistance. (Subtitle D State grants have not been available in 1982 and 1983.)
Safe Drinking Water Act of 1974, 42 U.S.C. 300f	The statute does not contain an explicit objective but is designed to assure that public water systems meet minimum standards for the protection of public health. The act requires the establishment of contaminant standards for drinking water (Part B), the establishment of regulations for underground injection (Part C), and the protection of sole source aquifers (Part C).	Environmental Protection Agency—Office of Drinking Water	States may assume primary enforcement responsibility for public water systems (PWS) to ensure compliance with national drinking water regulations if minimum Federal requirements are met. States may establish standards that are more stringent than Federal standards and may also set standards for substances not addressed by the Federal regulations. Regulatory authority for the Underground Injection Control (UIC) Program is also delegated to those States that establish programs that incorporate minimum Federal requirements. Programs may be more stringent than Federal requirements. Financial assistance is authorized to States for the development and implementation of both the PWS and UIC programs. States, municipalities, partnerships, associations, companies, corporations, or individuals may petition EPA to designate a sole source aquifer. Once an aquifer is so designated, any of these parties may petition EPA to review the potential of a project to contaminate the aquifer and create a significant hazard to public health.

Table 11.—Descriptions of Major Federal Statutes Relevant to the Protection of Groundwater Quality—continued

Statute	Objectives and provisions relevant to groundwater protection	Responsible Federal agencies	Relationship to the States
Surface Mining Control and Reclamation Act of 1977, 30 U.S.C. 1201	One purpose of the statute is to establish a nationwide program to protect society and the environment from the adverse effects of surface coal mining operations. The act requires the establishment of regulations for surface mining of coal (and the surface effects of underground coal mining) and authorizes reclamation of abandoned mine lands.	Department of the Interior—Office of Surface Mining Department of Agriculture—Soil Conservation Service	Regulatory authority is delegated to States that establish programs that incorporate minimum Federal requirements. Financial assistance is authorized to States for the development and implementation of such programs.
Toxic Substances Control Act of 1976, 15 U.S.C. 2601	The primary purpose of the act is to assure that chemical substances and mixtures do not present an unreasonable risk of injury to health or the environment.	Environmental Protection Agency—Office of Toxic Substances	Grants are available for States to establish programs to prevent or eliminate unreasonable risks to health or the environment in association with chemicals for which EPA is either unable or unlikely to take action under TSCA.
Toxic Substances Control Act of 1976, 15 U.S.C. 2601 (continued)			States may not establish or continue requirements (e.g., testing requirements or other regulatory actions) for chemicals for which EPA has prescribed rules or orders unless they are identical to the Federal requirements, prohibit the use of the chemical, or are adopted under the authority of other Federal laws. Exemptions may be approved by EPA under specified circumstances.
Uranium Mill Tailings Radiation Control Act of 1978, 49 U.S.C. 7901	The purpose of the statute is to stabilize and control both inactive mill tailings in a safe and environmentally sound manner and to minimize or eliminate radiation hazards to the public. The act requires the establishment of regulations for mill tailings at uranium or thorium processing mills and authorizes remedial actions at inactive sites.	Department of Energy Nuclear Regulatory Commission Environmental Protection Agency—Office of Radiation Programs	Regulatory authority for active uranium mills is delegated by NRC to the States that participate in the Agreement States Program. States may enter into cooperative agreements with DOE for remedial action projects; the agreements define the responsibilities of the parties. States are required to pay 10 percent of the costs, concur with the remedial action plan, and acquire private lands, as necessary, to be used as a permanent disposal site for residual radioactive materials.
Water Research and Development Act of 1978, 42 U.S.C. 7801	The purpose of the statute is to assist the Nation and the States through water resources science and technology to address a variety of water quality and quantity concerns. The act authorizes the establishment of a water resources research and tech-	Department of the Interior	States are required to designate the college or university at which the institute is established if there is more than one land grant college within a State. Two or more States may cooperate in the establishment of a regional institute.

Table 11.—Descriptions of Major Federal Statutes Relevant to the Protection of Groundwater Quality—continued

Statute	Objectives and provisions relevant to groundwater protection	Responsible Federal agencies	Relationship to the States
	nology institute at one college or university in each State, the support of a research and development effort for saline and other quality impaired water, and the establishment of a research assessment and technology transfer program.		Financial assistance for the institutes is available on a cost sharing basis, and matching grants are available for individual projects to supplement funds from non-Federal sources.

[a] Legislation passed subsequent to the Atomic Energy Act also authorizes Federal agency activities with respect to radioactive material. *The Reorganization Plan No. 3 of 1970* established the Environmental Protection Agency; responsibility for establishing environmental standards for radioactive materials was transferred to EPA from the Atomic Energy Commission. *The Energy Reorganization Act of 1974* established the Nuclear Regulatory Commission; NRC is responsible for licensing (and related regulatory functions) of nuclear reactors and facilities used to receive, store, and dispose of radioactive waste. *The Energy Reorganization Act of 1977* established the Department of Energy; DOE is responsible for the safe handling of DOE generated waste (including the decommissioning of contaminated Federal property), the selection, acquisition, and development of high-level waste repositories (pursuant to the Nuclear Waste Policy Act of 1982, Public Law 97-425), and the coordination of a national planning effort for the selection of low-level disposal sites (pursuant to the Low Level Radioactive Waste Policy Act, Public Law 96-573).

[b] This statute amends the Federal Water Pollution Control Act Amendments of 1972.

[c] Despite conflicting Federal judicial decisions about authority under Section 402 to regulate discharges into groundwater, a number of States have established such programs.

[d] The statute also creates a new Federal agency known as the Agency for Toxic Substances and Disease Registry within the U.S. Public Health Service of the Department of Health and Human Resources. In addition, CERCLA requires the promulgation of regulations for the assessment of damages from a release of oil or hazardous substances resulting in injury to, destruction of, or loss of natural resources. Executive Order 12316 delegates responsibility for the development of these regulations to the Department of the Interior. Advance notices of proposed rule-making were published by DOI in 1983 (43 FR 1084, Jan. 10, 1983 and 48 FR 34768, Aug. 1, 1983).

[e] Federal Environmental Pesticide Control Act of 1972, Public Law 92-516; Public Law 94-140, Nov. 28, 1975; Public Law 95-396, Sept. 30, 1978; and Public Law 96-539, Dec. 17, 1980.

[f] States may not authorize the sale or use of pesticides prohibited by EPA under FIFRA and may not impose or continue any requirements for pesticide labeling or packaging in addition to or different from those required by EPA. However, a State may provide registration for additional uses of federally registered pesticides formulated for distribution and use within the State to meet special local needs (if such use has not previously been prohibited by EPA).

[g] Regulations promulgated by the Department of the Interior for mining operations are authorized by both the Federal Land Policy and Management Act and the following statutes: The Mineral Leasing Act of 1920 (30 U.S.C. 181-287) and Materials Act of 1947 (30 U.S.C. 601-604) authorize mining of minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel, and clay on Federal lands; The U.S. Mining Laws (30 U.S.C. 22) authorize mining of "locatable" minerals such as gold, silver, lead, iron, and copper on Federal lands; The Geothermal Steam Act of 1980 (30 U.S.C. 1001-10025) regulates the development of geothermal steam on Federal lands.

Regulations for onshore oil and gas production have been promulgated by DOI and are administered by BLM under the authority of 17 laws, Attorney General's Opinions, and Secretary's Orders (43 CFR 3160). Authority is primarily derived from the Mineral Leasing Act, as amended and supplemented (30 U.S.C. 181 et seq.), and the Mineral Leasing Act for Acquired Lands, as amended (30 U.S.C. 351-359). The regulations contain provisions for protection of environmental quality including the protection against contamination of freshwater-bearing and other usable water containing 5,000 ppm or less of dissolved solids (43 CFR 3162.5). While not explicit, these regulations provide authority for groundwater monitoring and corrective and preventive activities. BLM is in the process of developing additional guidance to lessees for the protection of groundwater (Spector, 1984).

[h] As amended by Public Law 94-474, Oct. 11, 1976.

[i] The Council on Environmental Quality is responsible for issuing regulations regarding the preparation of environmental impact statements for use by Federal agencies.

[j] Legislation listed in footnote a is also applicable to this statute in that it regulates radioactive substances.

SOURCE: Office of Technology Assessment.

Table 12.—Groundwater-Related Activities of Federal Agencies

Department of Agriculture—Agriculture Research Service: ARS is conducting a limited number of research projects related to groundwater recharge and the impacts of agricultural activities on groundwater quality.

Department of Agriculture—Forest Service: The Forest Service is conducting environmental research projects on the fate and transport of pesticides (under the National Agricultural Pesticide Impact Assessment Program).

Department of Commerce—National Bureau of Standards: NBS is responsible for projects regarding the development of quality assurance standards that are used by other Federal agencies (e.g., EPA and DOE) to monitor the analytical performance of laboratories.

Department of Defense: The Army, Navy, and Air Force are participating in a program to identify and evaluate hazardous waste disposal sites on military installations and to undertake remedial actions at certain sites to control the migration of wastes (Installation Restoration Program).

The Army Toxic and Hazardous Materials Agency (USATHAMA), Air Force Occupational Environmental Health Laboratory, Air Force Engineering and Service Center, and Navy Energy and Environmental Support Activity provide technical support for the Installation Restoration Program and conduct research related to these efforts.

The Army Medical Bioengineering Research and Development Laboratory develops water quality criteria for certain munitions compounds.

The Army Corps of Engineers is working with EPA (under an interagency agreement) on design and construction of remedial action projects for CERCLA-designated sites. Research projects are also being conducted to support these activities.

Environmental Protection Agency—Office of Research and Development: EPA's Environmental Photographic Interpretation Center in Warrenton, VA, is responsible for acquiring and interpreting overhead imagery to support programs of EPA as well as other Federal agencies. Activities include conducting inventories of abandoned wells, mines, and hazardous waste sites, identifying failures in septic tank systems, and supporting emergency (e.g., oil spills) response activities.

EPA's Environmental Monitoring Systems Laboratory in Las Vegas, NV, the Robert S. Kerr Environmental Research Laboratory in Ada, OK, and the Environmental Research Laboratory in Athens, GA are conducting studies related to prediction (e.g., studies of those characteristics of aquifers that influence contaminant behavior) and monitoring (e.g., protocols for designing groundwater sampling programs). Other research activities related to source control, health effects, and treatment technologies are also being conducted at other EPA facilities.[a]

Department of Energy: Programs have been established for identifying and decommissioning nuclear materials storage and processing facilities that have become contaminated. Hydrogeologic investigations are being conducted at some of these sites. These programs include the Formally Utilized Sites Remedial Action Program and the Surplus Facilities Management Program.

Department of Housing and Urban Development: Environmental assessments are conducted related to housing projects; groundwater impacts are considered.

Department of the Interior—Bureau of Land Management: BLM is conducting inventories of hazardous waste sites on public lands.

Department of the Interior—National Park Service: Groundwater monitoring studies are conducted at various national parks to develop baseline data and to determine the extent and impacts of groundwater contamination from sources such as septic tanks and agricultural activities.

Department of the Interior—U.S. Geological Survey: The Water Resources Division of USGS is responsible for collection and analysis of hydrogeologic information (including groundwater data), maintaining computerized data bases, conducting research, and coordinating Federal activities with respect to the use and acquisition of water data.

Department of the Interior—Fish and Wildlife Service: FWS is conducting inventories of hazardous waste sites for all FWS lands and facilities.

Department of the Interior—Bureau of Indian Affairs: BIA is planning to conduct inventories of hazardous waste sites on or near Indian reservations.

National Science Foundation: The Division of Civil and Environmental Engineering, Directorate for Engineering (the Hydraulics, Hydrology, and Water Resources Program, and the Environmental and Water Quality Engineering Program) supports research projects on topics such as subsurface transport and wastewater treatment. Policy-related research is conducted by the Division of Research and Analysis, Directorate for Scientific, Technological and International Affairs.

Nuclear Regulatory Commission: Research projects are conducted related to the fate and transport of radioactive substances in support of regulatory activities.

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[a] EPA also supports several other types of activities related to groundwater. For example, EPA established a consortium called the National Center for Ground Water Research in September 1979. The consortium consists of the University of Oklahoma, Oklahoma State University, and Rice University; and the Ground Water Research Branch of the Kerr Laboratory serves as the center's immediate technical liaison. The primary objective of the center is to identify long-term problems and needs related to groundwater quality protection (e.g., transport and fate of contaminants and subsurface characterization) (Canter, 1982). EPA also provides funding to the Ground Water Clearinghouse at the Holcomb Research Institute. The clearinghouse contains an extensive file of groundwater models and assists the States in model selection and application (see OTA, 1982).

SOURCE: Office of Technology Assessment.

The Rivers and Harbors Act of 1899 prohibited discharge of refuse into navigable waters or their tributaries. In 1970, the statute was reactivated and became the basis for establishment of a permit program to regulate such discharges.[3]

The Water Pollution Control Act of 1948 and subsequent amendments in the 1950s and 1960s were concerned primarily with the establishment of surface water pollution abatement programs (e.g., construction of sewage treatment works).[4] One section of the act, however, recognized the connection between surface water and groundwater in authorizing the development of programs for "eliminating or reducing the pollution of interstate waters and tributaries thereof and improving the sanitary condition of surface and *underground waters* [italics added]."[5]

Two additional statutes, basically development-oriented, provide the Federal Government with authority over certain sources of groundwater contamination; they are the Reclamation Act of 1902 (RA) and the Atomic Energy Act of 1954 (AEA). The primary purpose of the Reclamation Act is to provide Federal assistance to Western States and local governments in the development of water supplies for municipal, industrial, agricultural, or other purposes. Some recent projects funded under the act have involved the removal and treatment of groundwater containing high concentrations of salt. Other irrigation projects have focused on controlling nitrate levels in groundwater. The Atomic Energy Act authorizes regulation of the development and use of atomic energy and requires that these activities be accomplished consistent with the health and safety of the public to the maximum extent possible. Groundwater contamination has been addressed in the context of regulatory and remedial action programs developed by the Nuclear Regulatory Commission, the Environmental Protection Agency, and the Department of Energy within the past 10 years for storage and disposal of radioactive substances.

Environmental Legislation: 1969 to the Present

The National Environmental Policy Act of 1969 (NEPA) was the first of many laws specifically enacted to protect the environment. It establishes a national policy on environmental quality and directs Federal agencies to use a systematic and interdisciplinary approach in decisionmaking and planning to ensure that environmental concerns are sufficiently considered. The act also requires Federal agencies to prepare environmental impact statements (EISs) for major Federal actions significantly affecting the environment. Although NEPA does not directly address groundwater, the EIS process provides a mechanism for evaluating the impacts of proposed projects (e.g., construction of a sewage treatment plant) and regulatory programs on groundwater.

Other environmental legislation passed in the early 1970s contains explicit wording for the protection of air, water, and oceans.[6] The objective of the Federal Water Pollution Control Act Amendments of 1972 (referred to as the Clean Water Act, CWA) is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[7] However, because of ambiguous language contained in key regulatory provisions of the statute and conflicting judicial interpretations,[8] its

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[3] 33 U.S.C. 407. Executive Order No. 11574, Dec. 23, 1970, 33 FR 19627, authorized the permit program (administered by the Department of the Army). The program was merged with the Dredge and Fill Permit Program under Section 404 of the Federal Water Pollution Control Act Amendments of 1972. In at least one instance, the statute has been used successfully by the Department of Justice to require the owner of a landfill to undertake remedial measures.

[4] 33 U.S.C. 466. For a discussion of the provisions of this statute, see U.S. House of Representatives, 1972 and U.S. Senate, 1971.

[5] 62 Stat. 1155, as amended, 33 U.S.C. 466. For a discussion see Miller, 1980.

[6] See the Federal Water Pollution Control Act Amendments of 1972, 33 U.S.C. 1251 et seq., as amended by the Clean Water Act of 1977; the Clean Air Act of 1970, 42 U.S.C. 1857 et seq., as amended; and the Marine Protection Research and Sanctuaries Act of 1972, 33 U.S.C. 1401 et seq., as amended.

[7] Section 101(a).

[8] Section 402 of the act establishes the National Pollutant Discharge Elimination System (NPDES), which requires that all point discharges into "navigable waters" be permitted. The legislative history of the statute suggests that the NPDES program is limited to surface water discharges. The permit program established by EPA is limited to surface water discharges. Federal courts have complicated the interpretation of the applicability of Section 402 to groundwater. The Seventh Circuit upheld EPA's authority to regulate underground discharges (*United States Steel Corp.* v. *Train*, 556 F. 2d 822, 7th Cir., 1977); two other courts denied EPA such authority (*United States* v. *GAF Corp.*, 389 F. Supp. 1379, S. D. Tex., 1975, and *Exxon Corp.* v. *Train*, 554 F. 2d 1310, 5th Cir., 1977).

Section 303 of the act authorizes establishment of State water quality standards. Although the language used in Section 303 does not mention groundwater standards explicitly, one court has upheld the authorapplication to groundwater has been limited. Nonetheless, provisions of the act are directly relevant to groundwater: Sections 208, 205(j), and 106 provide authorization and funding for State and regional monitoring and planning activities directed at both surface water and groundwater; Sections 201 and 311 authorize programs related to potential sources of groundwater contamination (land application of sewage treatment wastes and facilities used to store large quantities of oil, respectively); and Section 304 provides for development of water quality criteria.

In 1974, Congress enacted the Safe Drinking Water Act (SDWA) to "assure that water supply systems serving the public meet minimum national standards for protection of public health" (U.S. House of Representatives, 1974). To accomplish this goal, the act authorizes development and enforcement of drinking water standards for contaminants that may adversely affect human health, establishment of a program to regulate underground injection activities to protect drinking water supplies, and designation of sole-source aquifers to protect aquifer recharge areas. The act does not establish a comprehensive program for protection of *all* groundwater resources.

Subsequent legislation, enacted between 1976 and 1980, authorizes preventive measures (e.g., design and operating requirements) and federally funded remedial action programs for specific sources of groundwater contamination. These statutes include: the Resource Conservation and Recovery Act (RCRA), the Surface Mining Control and Reclamation Act (SMCRA), the Uranium Mill Tailings Radiation Control Act (UMTRCA), the Hazardous Materials Transportation Act (HMTA), the Hazardous Liquid Pipeline Safety Act (HLPSA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, commonly known as "Superfund"). The objectives or purposes of these statutes focus more generally on protection of public health and the environment than on protection of groundwater per se; and the regulatory programs that followed are inconsistent regarding groundwater protection (see chs. 6, 9, and 11).

In addition to source-oriented statutes, two others regulate the production and use of pesticides and

Photo credit: State of Florida Department of Environmental Regulation

FIFRA addresses the improper storage and disposal of pesticides and pesticide containers and residues.

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ity of EPA to require States to develop such standards in cases where a "clear hydrologic nexus" can be shown between surface water and groundwater (*Kentucky ex rel. Hancock* v. *Train*, 6 ELR 20689, E. D. Ky., 1976). For a more detailed discussion, see Wilson, 1976; Comments, 1978; and Tripp, et al., 1979.

other chemical substances. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) provides for registration and classification of pesticides (e.g., pesticides that may have unreasonable adverse environmental effects can be classified for "restricted use" in specified areas) and authorizes development of procedures for storage and disposal of pesticides and pesticide containers and residues. The Toxic Substances Control Act (TSCA) authorizes the regulation of chemical substances or mixtures that may present an unreasonable risk of injury to human health and the environment. Regulations regarding the manufacture, processing, distribution in commerce, use, or disposal can be promulgated. To date, however, the application of these two statutes to groundwater has been limited.

Three additional statutes relate to groundwater protection. Two of them focus on natural resources management. The Coastal Zone Management Act of 1972 (CZMA) provides Federal funds to States for development and implementation of management programs for coastal areas. Some State management programs are concerned with salt-water intrusion, a source of groundwater contamination.

The Federal Land Policy and Management Act of 1976 (FLPMA) authorizes the Bureau of Land Management (BLM) to manage public lands on the basis of multiple use and sustained yield principles. Although the act does not discuss groundwater explicitly, it does authorize the management of public lands in a manner that protects the quality of ecological, environmental, and water resource values. The statute provides BLM with explicit authority to regulate the use and development of public lands through permits, leases, licenses, published rules, and other instruments.[9] One use of public lands with the potential to contaminate groundwater is mining.[10]

The Water Research and Development Act of 1978 (WRDA)[11] authorizes the establishment of State Water Resources Research Institutes to conduct research and development relating to water resources, to disseminate information about these efforts, and to train scientists and engineers. Numerous projects funded under this program relate to groundwater quality.

SOURCES ADDRESSED BY FEDERAL STATUTES

This section focuses on current Federal programs and activities to address specific sources of groundwater contamination. It reviews the sources covered by each statute and the types of programs that each authorizes. Subsequent chapters describe in detail Federal investigatory activities (including monitoring), corrective actions, and preventive measures for specific sources.

Sources

Table 13 summarizes the relationship between sources known to contaminate groundwater and the Federal statutes. (The table is organized according to the OTA source categories described in ch. 2; see table 5.) Two significant points about sources and types of programs, based on table 13, are:

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[9] 43 U.S.C. 1732.

[10] Prior to the passage of FLPMA, BLM had established or proposed regulations governing certain activities on Federal lands under the authority of several mining laws, including the U.S. Mining Laws of the 1860s and 1870s, the Mineral Leasing Act of 1920, and the Materials Act of 1947. With the enactment of FLPMA and the reallocation of responsibilities for mining operations (among DOI's BLM, USGS, Minerals Management Service, and Conservation Division), BLM initiated efforts to revise the existing regulations so that they more clearly conformed with the objectives of the new legislation. Requirements for mining activities on Federal lands discussed in subsequent chapters reflect these changes; note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, in 43 CFR 3260 on Sept. 30, 1983.

The U.S Mining Laws (see 30 U.S.C. 22 et seq.) include the Lode Law of July 26, 1866 (14 Stat. 251), the Placer Law of July 9, 1870 (16 Stat. 217), and the Mining Law of May 10, 1872 (17 Stat. 91), as amended. These laws address all "locatable" mineral deposits such as gold, silver, uranium, lead, iron, and copper. The Mineral Leasing Act of 1920 (30 U.S.C. 181) and the Materials Act of 1947 (30 U.S.C. 601) address "leasable" minerals, including coal, phosphate, sodium, potassium, sand, gravel, and clay.

The Minerals Leasing Act and 16 other laws, Attorney General's Opinions, and Secretary's Orders address onshore oil and gas operations. Regulations for oil and gas production have been undergoing substantive revisions and were not analyzed in detail as part of this study. See table 11, footnote g,for a brief description of the relationship between the revised regulations and groundwater.

[11] Section 410 of the act repealed the Water Resources Research Act of 1964 (Public Law 88-379, 78 Stat. 329, 42 U.S.C. 1961 et seq.), as amended, and the Saline Water Conversion Act of 1971 (Public Law 92-60, 85 Stat. 159, 42 U.S.C. 1959 et seq.), as amended.

Table 13.—Relationship Between Sources of Contamination and Federal Statutes[a]

Sources	AEA	CWA	CZMA	CERCLA	FIFRA	FLPMA	HLPSA	HMTA	NEPA[b]	RA	RCRA	SDWA	SMCRA	TSCA	UMTRCA	WRDA[c]
Category I																
Subsurface percolation		E										A				
Injection wells (waste)				F								A				
Injection wells (non-waste)												A				
Land application		D		F							A					
Category II																
Landfills				F							A, B			A		
Open dumps (including illegal dumping)				F							B					
Residential (or local) disposal					C											
Surface impoundments				F		A					A		A			
Waste tailings						A									A	
Waste piles				F		A					A		A			
Materials stockpiles					C											
Graveyards																
Animal burial																
Aboveground storage tanks		A		F							A			A		
Underground storage tanks		A		F							A			A		
Containers				F	C						A			A		
Open burning/detonation sites				F	C						A					
Radioactive disposal sites	A														A, F	
Category III																
Pipelines				F			A									
Materials transport/transfer operations				F				A								
Category IV																
Irrigation practices		C, E														
Pesticide applications		C, E			A											
Fertilizer applications		C, E														
Animal feeding operations		C, E														
Deicing salts applications																
Urban runoff		C, E														
Percolation of atmospheric pollutants																
Mining and mine drainage		C, E				A							A, F			
Category V																
Production wells						A						A				
Other wells (non-waste)						A										
Construction excavation		C, E														
Category VI																
Groundwater-surface water interactions		C, E														
Natural leaching										F						
Salt-water intrusion/brackish water upconing		C, E	E													

[a] Key:
A = Requires compliance with specified Federal requirements (some programs in this group may be implemented by States if they meet certain Federal criteria).
B = Authorizes funding of optional State programs that address specific sources.
C = Establishes Best Management Practices (BMPs) or recommended procedures for certain sources.
D = Establishes Federal criteria that must be met in order to receive funds for specific projects related to a source of contamination.
E = Establishes a grant program to States (funds may be used at the State or local level to address contaminants or sources).
F = Funds Federal cleanup of contaminated groundwater and associated sources.

[b] NEPA does not apply to any particular source. The environmental impacts of projects involving the use of Federal funds may be subject to Federal agency review.

[c] WRDA does not apply to any particular source. The act provides research funds to States. Projects may focus on particular sources.

SOURCE: Office of Technology Assessment

1. **existing Federal statutes do not cover all known sources of contamination discussed in this study;** and
2. **sources are not treated in a uniform manner by the programs authorized by Federal legislation.**

Table 13 indicates that most sources (all but 4) are covered by at least one statute and that 18 sources are covered by more than one statute.[12] But the coverage is not as comprehensive as it appears in the table. Most Federal statutes limit coverage by defining only subsets of facilities and/or activities of a given source type that are subject to their respective requirements. These definitions are based on various criteria, such as the presence of certain contaminants (e.g., hazardous wastes). Moreover, the statutory definition of sources is sometimes narrowed further by the regulations issued by the Federal agencies responsible for implementing the statutes.[13] Descriptions of the sources covered by Federal programs is compiled in appendix B.1, which also indicates whether detection, correction, or prevention provisions have been established for each source. These provisions are discussed in chapters 6, 9, and 11, respectively.

Based on the information in appendix B.1 and the data on sources presented in chapter 2, a preliminary list of sources of groundwater contamination which are not currently being addressed by Federal statutes would include:

- surface impoundments used to contain non-hazardous wastes (e.g., impoundments used in agriculture);
- waste piles and materials stockpiles used to store non-hazardous wastes (except pesticides);
- tanks (aboveground and underground) used to contain non-hazardous wastes;
- non-coal mining activities on private lands; and
- pipelines not regulated by the Hazardous Liquid Pipeline Safety Act.[14]

Given the limitations of OTA's information on sources, this list should not be viewed as either exhaustive or rigid. Further, some States are addressing some of these sources. Thus, a thorough assessment of source coverage necessitates examination of both Federal and State activities. (See ch. 4 for a discussion of State coverage of sources.)

Types of Programs

In addition to the sources that are covered by Federal statutes, it is also important to look at the types of programs authorized by the laws (table 13). These range from mandatory permit or licensing programs to such voluntary programs as development of Best Management Practices for new or existing sources of contamination. Other programs direct the Federal Government to undertake remedial action at inactive or abandoned sites that either have contaminated or have the potential to contaminate groundwater.

The Federal Government's general approach to prevention and control of contamination from sources with hazardous wastes and other toxic materials (e.g., mining operations and injection wells) **differs from the one used for most non-hazardous waste sources** (e.g., sanitary landfills in Category II) **and non-waste sources** (e.g., agriculture-related sources in Category IV and all sources in Category

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[12] It is important to point out that the applicability of CERCLA to sources of contamination as presented in table 13 is based on the types of sources currently on the National Priorities List. It is certainly possible to use CERCLA to deal with other sources that release any hazardous substance, pollutant, or contaminant. Under CERCLA, hazardous substances are those designated by CWA (Sections 311(b)(2)(A) and 307(a)); RCRA (Section 3001); CERCLA (Section 102); the Clean Air Act (Section 112); and TSCA (Section 7). A pollutant or contaminant includes "any element, substance, compound, or mixture . . . that will, or may reasonably be anticipated to cause death, disease, behavioral abnormalities, cancer, genetic mutation, physiological malfunctions, or physical deformations in organisms or their offspring" (Section 104(a)(2)). Petroleum (including crude oil and any fraction thereof) and natural gas, natural gas liquids, liquefied natural gas, and synthetic gas usable for fuel are explicitly excluded from the definition of hazardous wastes.

[13] For example, Section 3001 of RCRA requires EPA to promulgate regulations identifying the characteristics of hazardous wastes and listing particular wastes. The statute explicitly defines hazardous wastes as solid wastes which may: "(A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed [42 U.S.C. 6903(S)]." The listing criteria developed by EPA (see 40 CFR 261) have been subject to much discussion and criticism in that they limit the universe of hazardous wastes currently being regulated. See OTA, 1983.

[14] Five more sources not covered by Federal statute are: percolation of atmospheric pollutants, graveyards, animal burial grounds, deicing salts, and household disposal. The OTA analysis in ch. 2 did not identify these sources as major contributors to groundwater contamination nationwide.

VI). The major distinction is that the types of programs applicable to non-hazardous waste and non-waste sources rely on use of voluntary design or operating procedures (e.g., Best Management Practices), and those associated with hazardous or toxic substances establish mandatory requirements (e.g., permit programs). Significantly, programs with mandatory requirements focus on point sources of contamination, and voluntary approaches are generally used with non-point sources.

The types of programs authorized by Federal statutes that are relevant to sources of contamination can generally be described as follows (refer to table 13):

- *Programs that establish mandatory requirements (e.g., design, operation, monitoring, and/or corrective action requirements) for sources of groundwater contamination:* Table 13 indicates that 11 statutes authorize development and enforcement of such requirements. Site-specific permits or licenses are required by several of these laws (i.e., Subtitle C of the Resource Conservation and Recovery Act, the Safe Drinking Water Act, the Surface Mining Control and Reclamation Act, the Atomic Energy Act, and the Uranium Mill Tailings Radiation Control Act). In addition, some statutes specify that regulatory authority may be delegated to States that meet certain Federal criteria and/or enter into specific agreements with Federal agencies (table 10).
- *Programs that authorize Federal funding of optional State programs for specific sources:* Subtitle D of the Resource Conservation and Recovery Act is in this category. States are awarded grants to develop solid waste management plans if the plans meet specified criteria for sanitary landfills.
- *Programs that establish Best Management Practices (BMPs) or recommended procedures for design and operation of certain sources:* Best Management Practices for certain non-point sources have been developed under the Clean Water Act (e.g., agriculture-related sources in Category IV). Procedures are recommended for the storage of pesticides and disposal of pesticide residues under FIFRA (e.g., some Category II sources).

Photo credit: U.S. Geological Survey

The storage and disposal of radioactive substances is regulated under the Atomic Energy Act. This photograph shows vaults used to contain low-level radioactive wastes in shallow land burial sites.

- *Programs that establish Federal design and operating criteria that must be met by owners or operators in order to receive funds for specific projects (or project components) that are potential sources of contamination:* This category includes the Innovative and Alternative Technology provisions of Section 201 of the Clean Water Act for land application of sludge and wastewater from sewage treatment.
- *Programs that establish grant programs to States for water planning and management activities:* Under the Coastal Zone Management Act, grants are awarded to States for development and implementation of coastal zone management plans. Plans may provide for

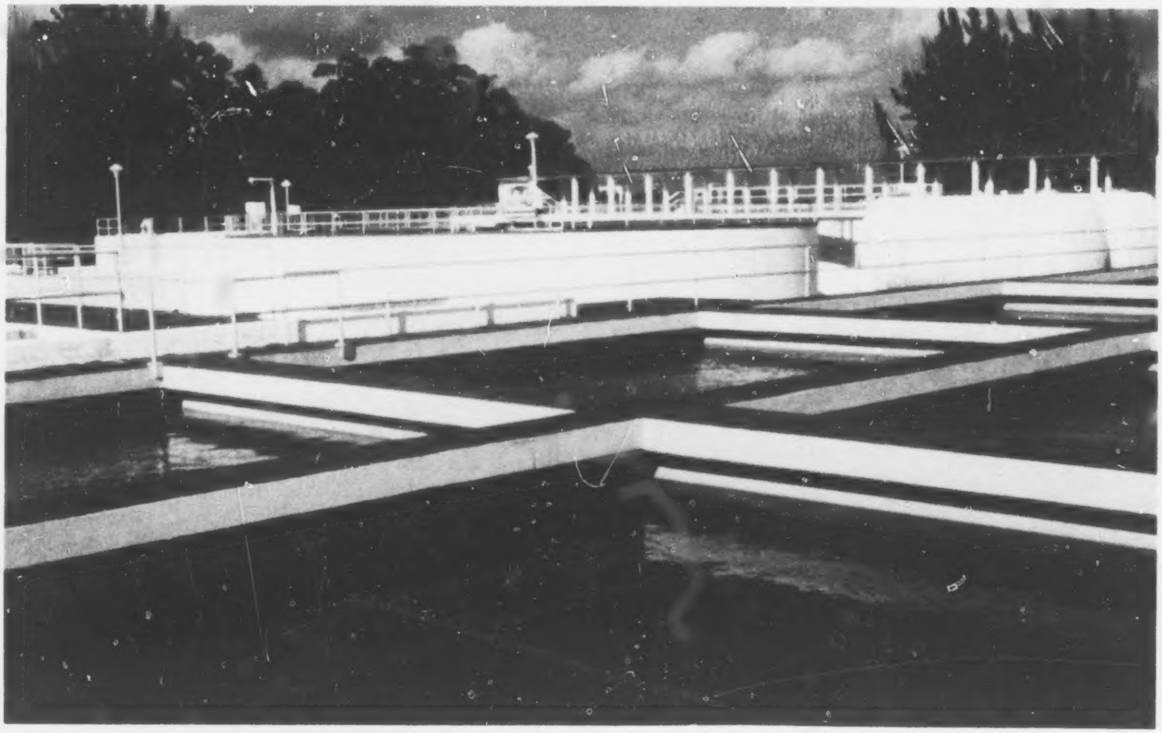

Photo credit: State of Florida Department of Environmental Regulation

The sludge and wastewater from the treatment of municipal sewage are often subsequently disposed of through land application.

minimizing impacts of salt-water intrusion by controlling land and water uses. Section 208 of the Clean Water Act also provides for State water planning and management activities. Funds may be used at the State or local level on non-point sources that cause groundwater quality problems.

- *Programs that fund Federal remedial actions for sources of groundwater contamination:* These statutes include the Comprehensive Environmental Response, Compensation, and Liability Act, the Surface Mining Control and Reclamation Act, and the Uranium Mill Tailings Radiation Control Act. Some water development projects funded under the Reclamation Act also involve treatment of contaminated groundwater.

Two statutes not included above are the National Environmental Policy Act (NEPA) and the Water Resources Development Act (WRDA). Although NEPA is not directed at particular sources, environmental impact statements may be required for federally funded projects that are potential sources of groundwater contamination (e.g, construction of a highway or housing development). WRDA also does not address specific sources, but research projects funded under the act may relate to sources of contamination.

WATER QUALITY STANDARDS

Water quality standards specify the limits beyond which substances in the environment may cause adverse impacts. Standards may be developed strictly to protect public health, the environment, or uses of groundwater, or to balance the benefits and costs of achieving different levels of protection.

Water quality standards may be applied in programs to detect, correct, or prevent groundwater contamination. *Detection programs* may use water quality standards to determine whether there is a problem that warrants action. For example, under the Safe Drinking Water Act, public water supplies are monitored for contaminants specified by the National Interim Primary Drinking Water Regulations (NIPDWR); if concentrations exceed specified levels, certain steps must be taken, including public notification. Under the Resource Conservation and Recovery Act, hazardous waste landfills must be monitored for particular substances; if concentrations exceed specified levels, more intensive monitoring is required, possibly leading to corrective action. *Correction programs* may use water quality standards in determining cleanup goals (e.g., under RCRA, the NIPDWR may be used to set cleanup requirements; in the absence of drinking water standards, background levels or an alternative concentration limit may be used on a case-by-case basis). *Prevention programs* may use water quality standards in defining unacceptable levels of contamination (e.g., under the Clean Water Act, NIPDWR may be used to limit discharges to groundwater from the land application of wastewater, depending on the use of the groundwater).

In addition to standards that relate correction or prevention programs to the actual quality of water that may result from a particular activity, technology-based approaches such as design and operating requirements are also often used. In 1972, with passage of new water quality legislation, the Federal Government de-emphasized quality-based pollution control, given the difficulties in linking allowable releases of pollutants from point sources to the quality of surface waters.[15]

Federal statutes require standards for drinking and surface water quality, but *not* specifically for groundwater (see also the section *Concentration and Frequency Data in Relation to Government Standards,* ch. 2). For drinking water, there are 22 Federal mandatory minimum standards for public drinking water supplies under the Safe Drinking Water Act National Interim Primary Drinking Water Regulations (Maximum Contaminant Levels, MCLs). Federal minimum standards are not set for surface water quality; rather, the Federal Government provides general guidance to the States on setting standards for specific water uses through Ambient Water Quality Criteria under the Clean Water Act. These criteria include numeric and narrative water quality standards to protect public health and welfare, aquatic life, and recreational use. If a State does not adopt as a minimum the NIPDWR or federally approved surface water quality standards, the the Federal Government is authorized to assume responsibilities for standards in the State.

The Federal Government also provides guidance on standards for selected substances in drinking water through National Secondary Drinking Water Regulations and Recommended Maximum Contaminant levels (RMCLs) under the Safe Drinking Water Act and Health Advisories (formerly, Suggested No Adverse Response Levels, SNARLs). National Secondary Drinking Water Regulations cover selected contaminants and concentrations that may adversely affect either odor, appearance, or the public welfare. RMCLs are non-enforceable *health goals* for public water supplies and are set at levels that would result in no known or anticipated health effects, including an adequate margin of safety.[16] Health Advisories cover selected contaminants found in drinking water for which there are no Federal requirements.

As shown in appendix C.3, which lists the specific substances covered by Federal and/or State

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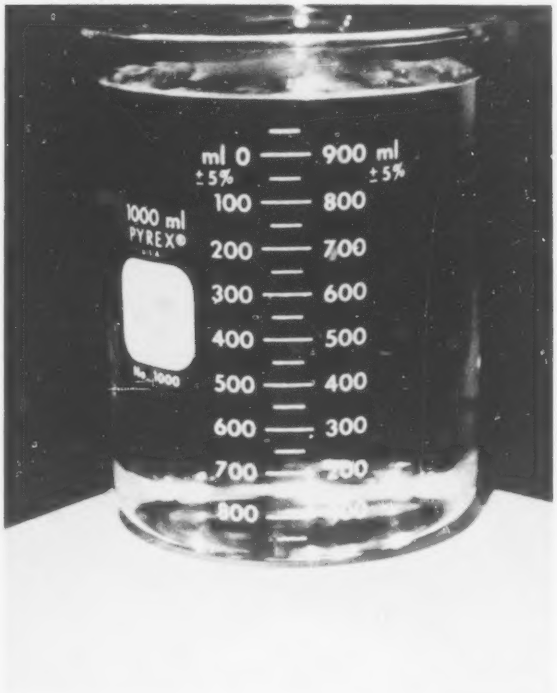
[15] For a more detailed discussion of the legislative history of the Federal transition to technology-based standards with respect to surface water, see Copeland, 1983; and Davis, et al., 1976.

[16] The first RMCLs were proposed for nine volatile synthetic organic chemicals (VOCs) in the Federal Register on June 12, 1984. MCLs for these chemicals will be proposed when the RMCLs are finalized. MCLs are to be set as close to the RMCLs as feasible but will also be based on a balancing of health protection with other factors including the availability and costs of treatment technologies.



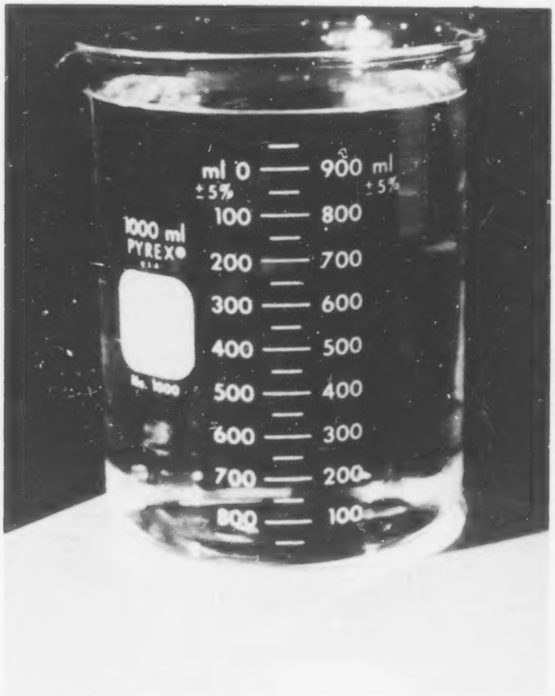


Photo credits: State of Florida Department of Environmental Regulation

An *underground source of drinking water* is in part defined under the Safe Drinking Water Act as containing fewer than 10,000 milligrams per liter (mg/l) of total dissolved solids (TDS) (left). Good tasting water has less than 1,500 mg/l of TDS (right).

water quality programs, different programs generally apply to different substances. When a substance is covered by more than one program, minimum requirements or suggested concentrations differ from program to program. Such differences arise because concentrations developed under the Safe Drinking Water Act reflect health concerns as well as technology-related and economic factors, while Ambient Water Quality Criteria consider only health or environmental impacts. Further, health information from Ambient Water Quality Criteria includes the ingestion of aquatic life and not just adverse impacts from drinking water.

MECHANISMS FOR INTERAGENCY COORDINATION

The multiplicity of both groundwater-related laws and the agencies responsible for their implementation has fragmented Federal protection of groundwater quality. Further, within certain agencies, numerous offices are responsible for groundwater activities (refer to tables 11 and 12). Because no single agency or organization is responsible for coordinating all groundwater programs and activities, three mechanisms for interagency coordination are used and are described below. Activities to be coordinated are both regulatory, primarily focusing on sources of contamination, and non-regulatory, including data collection, technical assistance, and research and development.

USGS Coordinating Committees

The U.S. Geological Survey and other Federal agencies have entered into Interagency Agreements (IAGs) or Memoranda of Understanding (MOUs), which establish coordinating committees comprised of representatives of each agency. The committees coordinate plans and activities of mutual interest, including water-related issues (e.g., hydrologic investigations), and exchange data and information. Table 14 lists the agencies with which USGS has established committees, their effective dates, and their purposes. As table 14 indicates, the scope of these committees extends beyond groundwater-related issues. Nonetheless, the committees provide a forum for raising groundwater concerns and have led to additional agreements that focus on groundwater quality.

Program-Related Agreements

IAGs and MOUs established between Federal agencies also relate to implementation of statute-specific programs or activities concerning groundwater protection, such as provision of technical assistance for hydrogeologic investigations (e.g., groundwater monitoring) or for corrective actions. Several agreements described below are examples of the types of programs that have been arranged:

- The Environmental Protection Agency and the Army Corps of Engineers have entered into an agreement whereby the Corps provides both management and technical assistance to EPA with respect to implementation of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Table 14.—Committees for Program Coordination Between USGS and Other Federal Agencies

Federal agency	Effective date	Purpose
Department of Agriculture—Soil Conservation Service	5/12/73, revised 1/21/76	To exchange data and information, to cooperate in programs, and to coordinate fields of operation such as geologic, soil, chemistry, mineralogic erosion, watershed, river basin, flood, land resources, wetland, hydrologic, sediment, snow, topographic surveys, and mapping and resource analysis.
Department of Commerce—National Oceanic and Atmospheric Administration	2/20/72	To coordinate related programs including seismology, marine geology and geophysics, hydrology, mapping, and earth resource surveys from space.
Department of Energy—Office of Energy Research	11/8/78	To develop an exchange of information on research, to resolve issues of policy and responsibilities, to arrange cooperation in operation of programs, and to exchange budget information for cooperative programs.
Department of the Interior—Bureau of Land Management	3/6/74, revised 9/9/82	To coordinate related programs including lease management, environmental studies, land and resource classification, mapping and surveys, and water resource investigations.
Department of the Interior—Bureau of Mines	12/9/77	To clarify the primary roles of the agencies and to establish mechanisms for coordination, including resource classification, data storage, and data standards.
Department of the Interior—Bureau of Reclamation	4/15/83	To coordinate related programs including mapping, land and water resource planning, water resources investigations and research, geologic investigations and research, and information systems.
Department of the Interior—Office of Surface Mining	7/26/78	To coordinate data exchanges and related programs, including monitoring, hydrologic studies, land use, geologic mapping, data systems, and programs and budgets.
Environmental Protection Agency	8/5/81	To provide a mechanism to coordinate programs and plans, provide for technology transfer and data exchanges, arrange for cooperation and support of programs of mutual interest, arrange exchange of budget and planning information, act as a clearinghouse for EPA/USGS contacts, and provide information on existing and future MOUs and IAGs between the agencies.

SOURCE: USGS, 1983.

Under the agreement, the Corps is responsible for managing the design, construction, and operation of remedial actions at hazardous waste sites for which EPA (as opposed to a State) assumes lead responsibility.

- An agreement between EPA and USGS specifies the cooperation and extent of assistance that USGS will provide EPA's Office of Waste Programs Enforcement in gathering information and assessing the hydrology and geology of hazardous waste sites. The types of assistance that USGS can provide include but are not limited to: provision of data from USGS files on groundwater systems near a hazardous waste site; technical assistance on the design or review of investigative studies; and comments on remedial action designs and the predicted effectiveness of such actions.
- Another agreement between EPA and USGS is for USGS assistance to EPA in fulfilling its responsibility to designate sole source aquifers under Section 1424(e) of the Safe Drinking Water Act. USGS provides EPA with the following: aquifer descriptions, evaluations of aquifer vulnerability to contamination, background information on drinking water sources and alternative water supply sources, and projections of water consumption.

Water Data Coordination

A 1964 directive issued by the Office of Management and Budget, Circular No. A-67, prescribes guidelines for "coordination of Federal activities in acquiring water data from streams, lakes, reservoirs, estuaries, and groundwater." The Department of the Interior was assigned lead responsibility. In October 1964, the Office of Water Data Coordination was established within the Water Resources Division of USGS to implement provisions of the directive. Two advisory committees, the Interagency Advisory Committee on Water Data and the Advisory Committee on Water Data for Public Use, were also established to assist USGS.

EFFORTS TO IMPROVE CAPABILITIES

Improving Federal and State capabilities to protect groundwater quality requires a variety of activities, including financial assistance, technical assistance, and research and development. The following discussions generally describe Federal activities and programs in these areas.

Financial Assistance

A number of Federal statutes examined in this study authorize grant programs for the States. None of the provisions, however, is earmarked exclusively for groundwater activities.

As indicated in table 11, the States may be delegated authority to implement certain regulatory programs, and grants are provided for these purposes. For example, Subtitle C of the Resource Conservation and Recovery Act, the Surface Mining Control and Reclamation Act, and the Underground Injection Control (UIC) Program of the Safe Drinking Water Act have such provisions. Funds under these programs are not limited to groundwater-related activities.

Under other statutes, the States are awarded grants for planning and other water-related activities. For example, Section 208 of the Clean Water Act authorizes the States or regional planning agencies to prepare water quality management plans to identify and propose solutions to water quality problems; the plans, however, are not legally binding. Section 208 was designed explicitly to address non-point sources such as agriculturally and silviculturally related sources (e.g., irrigation return flows), mine-related sources, construction activities, and salt-water intrusion.[17] Funding for Section 208 activities ended in 1981, but additional funding for State water quality activities is now available through Sections 106 and 205(j) of the Clean Water Act. Funding for other programs (e.g., the Coastal Zone Management Act, RCRA

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[17] Section 208(b)(2)(F)—(K).

Subtitle D, and the Rural Abandoned Mine Program) has either been reduced or eliminated in recent years.

Technical Assistance

Programs within EPA, USGS, and the Soil Conservation Service (SCS) provide technical assistance on groundwater quality to the States, individuals, and other Federal agencies. For example, EPA's Office of Drinking Water advises the States and other authorities in determining the types of response appropriate to contamination incidents. Health Advisories for 22 contaminants have been developed; they suggest the level of a potential contaminant in drinking water at which adverse health effects would not be anticipated for the most sensitive members of the population. Other kinds of technical assistance activities at EPA include preparation of special guidance manuals for EPA program implementation (e.g., RCRA permit writer manuals) and guidance on laboratory testing.

USGS technical assistance to the States and other Federal agencies includes a variety of programs (e.g., the Hazardous-Waste Hydrology Program, the Assistance to Other Federal Agencies Program, and the State Cooperative Program) (Chase, et al., 1983). USGS assists in the development of both Federal and State regulations and standards for managing disposal of hazardous wastes and assists Federal agencies on toxic waste cleanup under RCRA and CERCLA programs. Through the National Water-Data Storage and Retrieval System (WATSTORE) and National Water Data Exchange (NAWDEX), USGS maintains and provides access to data on surface water and groundwater quality and quantity and to meteorological data. USGS study and research results are disseminated through numerous publications. USGS also provides training programs for Federal, State, and local agencies on hydrologic investigations. (Ch. 6 describes selected USGS activities in more detail.)

Although SCS programs are not directed specifically at groundwater, technical assistance to the States, counties, and individuals is provided through the Rural Clean Water Program and the development of Best Management Practices to minimize adverse impacts on water quality. Financial assistance to individuals may be provided through the Agricultural Stabilization and Conservation Service (ASCS) to implement some Best Management Practices.

In compliance with Section 104 of CERCLA, the Agency for Toxic Substances and Disease Registry was established as part of the Centers for Disease Control (CDC) in April 1983.[18] CDC is currently working with the National Governors' Association (NGA) to implement Section 104(i)(3). Under the section, the Agency for Toxic Substances and Disease Registry is required to maintain a complete list of areas closed to the public or otherwise restricted in use because of toxic substance contamination. A Memorandum of Understanding is currently being negotiated between CDC and EPA on the responsibilities of each for administering provisions of Section 104. CDC has also designated public health advisors in EPA's regional offices to assist in assessing health impacts at uncontrolled hazardous waste sites.

Other Federal agencies also have designated responsibilities under Section 104:

1. The Food and Drug Administration conducts field investigations and analyses of food chain crops affected by CERCLA sites (Section 104(i)(4)).
2. The National Library of Medicine is conducting an inventory of literature, research, and studies on health effects of toxic substances (Section 104(i)(2)).
3. The National Institute of Environmental Health Sciences analyzes compounds found at CERCLA sites (Section 104(i)(4)).

Federal Research and Development Concerning Groundwater Quality

At least 26 Federal organizations are conducting or are planning to conduct research and development (R&D) studies on groundwater quality. Table 15 lists the organizations and categorizes their major groundwater quality R&D activities. Most of the work that is done requires an understanding of groundwater flow systems.

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[18] 48 FR 17651-17652. The agency was established following settlement of a lawsuit brought by the Environmental Defense Fund (EDF) against the Department of Health and Human Services for their failure to comply with Section 104 of CERCLA. See Reisch, 1983.

Table 15.—Federal Involvement in Groundwater Quality Research and Development[a]

	Categories of groundwater quality R&D[b]									
Federal organization	1	2	3	4	5	6	7	8	9	10
National Science Foundation			X		X				X	
Department of Agriculture										
Agricultural Research Service			X			X				
Forest Service			X							
Soil Conservation Service					X	X			X	
Department of Commerce										
National Bureau of Standards	X									
Department of Defense										
Army Corps of Engineers		X			X	X			X	X
Army Medical Bioengineering R&D Laboratory	X									
Army Toxic and Hazardous Materials Agency	X								X	
Department of Energy		X								
Department of the Interior										
Bureau of Indian Affairs					X					
Bureau of Land Management					X					
Bureau of Reclamation					X	X				
Fish and Wildlife Service					X					
Geological Survey		X	X	X	X	X	X			
National Park Service				X	X					
Office of Surface Mining					X		X			
Office of Water Policy		X	X					X	X	
Environmental Protection Agency										
Environmental Monitoring Systems Laboratory	X		X							
R.S. Kerr Environmental Research Laboratory			X							
Environmental Research Laboratory			X							
Office of Pesticide Programs			X							
Office of Radiation Programs	X				X					
Office of Research and Development		X	X		X				X	X
Office of Solid Waste					X					
Office of Water								X		
Nuclear Regulatory Commission		X	X							

[a] The listing is not exhaustive but covers principal programs and activities related to groundwater quality R&D. Examples of other Federal R&D activities omitted here address quantity estimates, use patterns, source inventories, recharge, information exchange, socioeconomic effects of alternative supplies, and environmental effects of contamination.

[b] Key for categories of groundwater research and development:
1—Standards certification, quality assurance, and water quality criteria.
2—Hydrogeologic investigations and dynamics of groundwater flow.
3—Subsurface fate and transport of contaminants.
4—Background monitoring of groundwater quality.
5—Detection of groundwater contamination from various sources.
6—Salt-water intrusion and salinity problems.
7—Surface water-groundwater interactions.
8—Control of groundwater contamination from various sources.
9—Treatment technologies.
10—Evaluation of alternatives.

SOURCE: Office of Technology Assessment.

The most diverse research programs—in terms of the number of R&D categories involved—are those of the Environmental Protection Agency (the Office of Research and Development is most active), the U.S. Geological Survey, and the Army Corps of Engineers. Information made available for this study does not allow a detailed breakdown of projects within all the agencies.

Institutional involvement is highest—in terms of the number of organizations conducting research in a particular category—in the detection of groundwater contamination and in subsurface fate and transport of contaminants. Detection efforts generally involve point sources (e.g., waste piles, landfills, mine drainage, underground injection wells, surface impoundments, and septic tanks), but some efforts are also being directed toward nonpoint sources (e.g., salt-water intrusion, farm runoff, and pesticide applications). Several organizations are also involved in standards certification and quality assurance, hydrogeologic investigations, and treatment technologies.

As of 1978, the Federal budget for all water research was approximately $225 million but only $10 million to $12 million was spent on groundwater R&D (U.S. House of Representatives, 1978). Data available for this study are not sufficient for estimating current Federal expenditures either on groundwater quality R&D overall or on specific categories of R&D. In general, groundwater R&D expenditures are not identified as such, and without detailed budget information, the extent and focus of Federal groundwater R&D activities cannot be assessed.

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Chapter 4

State Institutional Framework To Protect Groundwater From Contamination

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Chapter 4

State Institutional Framework To Protect Groundwater From Contamination

CHAPTER OVERVIEW

OTA State Survey

Information on the States presented in this report is based primarily on a survey of all the States conducted by OTA from June to September 1983. The objectives of the questionnaire, which was sent to the State Governors, were to obtain a common information base for assessing the extent to which individual States use available techniques for handling existing groundwater contamination problems and to learn the status of State efforts concerning groundwater quality protection. All 50 States responded. Summary information derived from State responses is discussed in this chapter regarding the institutional framework; technically oriented issues related to specific detection, correction, and prevention activities are covered in chapters 7, 10, and 12, respectively.

State responses to the OTA survey reflect the views of State personnel involved in groundwater quality programs. Questionnaires received by the Governors' offices were forwarded to the State agencies with groundwater quality responsibilities. Responses were prepared by a single agency in 36 States, although several programs within the agency often participated. Fourteen States coordinated their responses with more than one agency. The extent to which the response of a single agency reflects State activities is highly variable, depending on the relative role of that agency in dealing with groundwater contamination. In view of the fact that many States are actively developing or revising their contamination programs, responses reflect program status only as of the date of the questionnaire, i.e., summer 1983.

Survey questions were divided into eight categories: sources, detection, corrective actions, prevention, improving capabilities, State policies, Federal-State relations, and impacts. Emphasis was on the detection and correction of *existing* contamination. Thus, further investigation would be required for a detailed analysis of prevention.

A list of the State agencies that responded and a copy of the questionnaire are presented in appendixes C.1 and C.2, respectively. Because many of the questions asked in the survey are open-ended, the fact that only a few States commented on a particular issue does not necessarily imply that the issue is not of concern to other States. Issues raised by the State responses should thus be interpreted as potentially important to additional States as well.

State questionnaire responses discuss most, but not all, of the sources of contamination, techniques for hydrogeologic investigations, and correction alternatives presented in the technical chapters of this report. The technical chapters have additional coverage because they continued to evolve after the questionnaire was distributed. Nevertheless, State responses provide a factual and comprehensive basis for analysis of State activities and concerns.

State Institutional Framework

In this chapter, State perceptions of groundwater contamination problems and a general description and assessment of their efforts to handle these problems are presented.[1] The following topics are discussed:

- State perceptions of groundwater contamination problems;
- overview of State activities to protect groundwater quality from contamination by selected sources;

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[1] For more detailed accounts of selected State programs see GAO, 1984; Pye, et al., 1983; Henderson, et al., 1984; National Conference of State Legislatures, 1983; and Magnuson, 1981.

- State efforts to improve capabilities to deal with groundwater contamination;
- State perspectives on Federal programs, including Federal water quality standards and guidance; and
- State strengths, problems with their programs to protect groundwater quality, and types of desired Federal assistance.

Conclusions drawn from this information are summarized below.

Problems with groundwater quality have been identified in every State, and all the States are working to improve their efforts to deal with contamination. State efforts to protect groundwater quality have increased markedly in the past 2 years; for example, the States are beginning to look at more types of activities and facilities that are potential sources of groundwater contamination than previously. However, there are differences in the ways the States perceive and address contamination problems—different States have different problems, priorities, capabilities, and approaches. Some sources of contamination are receiving more attention than others. Some potential sources are not being addressed by most of the States. The States are also at different stages in developing and implementing programs, and generally, are at the very early stages.

The States have been more successful addressing some types of sources of contamination than with others: new v. old, active v. inactive, large v. small, concentrated v. widespread, point v. non-point, non-agricultural v. agricultural, and industrial wastes v. residential wastes. They have also been generally more successful with sources for which there is a Federal mandate for action or for which they have explicit authority. In general, the focus of State programs is on point sources of wastes, rather than on non-point sources and non-waste sources. More States give priority to, and have developed programs for, prevention rather than detection or correction.

All the States recognize problems with their efforts to protect groundwater from contamination. The problems relate primarily to resources (e.g., funding, technical expertise, and information and data) and authority to develop and implement programs. Lack of authority to deal with some sources is considered a serious problem by almost 40 percent of the States. Although there is a general lack of uniformity among the States about the sources for which they do not have authority, at least two sources—underground storage tanks and agricultural practices—were highlighted by one-half the States noting problems with authority.[2]

Current Federal laws and programs are generally helpful to the States. But the level of support is not perceived as adequate by most States, nor is support directed at all the specific areas where the States have identified problems (e.g., Federal guidance on water quality standards is perceived as insufficient by many States). In some cases, the States feel that Federal initiatives have actually hindered State efforts.

Problems have been created for some States by some Federal programs. For example:

- programs have resulted in the transferring of surface water quality problems to groundwater;
- resources have been shifted from groundwater issues to other Federal priorities;
- programs have failed to provide explicit

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[2] The States obtain authority to address sources of groundwater contamination through a variety of mechanisms. For example, a State may establish authority through legislation specifically addressing a source (e.g., regulating solid waste landfills); legislation specifically addressing groundwater quality (e.g., regulating discharges to groundwater); or more general water quality legislation that enables a State to protect the quality of State waters (defined to include groundwater in many States). State legislation may be passed in response to Federal laws or programs, or legislation may be developed by the State independently of any Federal activities. For example, Federal laws may require that States establish a program (or the Federal Government will develop a program for the State, as in the Safe Drinking Water Act) or a Federal law or program may offer a State financial assistance if the State establishes a program meeting Federal criteria, as in the Coastal Zone Management Act.

Once a State has established authority to address groundwater contamination, specific programs are developed (unless they are specifically described in the legislation) and implemented. Program development may involve approval of administrative regulations and guidelines that describe the scope of the program in greater detail than the enabling legislation. For example, a State may have a law that authorizes the establishment of standards for groundwater quality, but the specific standards and the exact circumstances in which they are applied are established in administrative rules or regulations. Such administrative rules and regulations may require some type of approval by the State legislature, or they may be up to the discretion of the implementing agency. State program implementation may require that the legislature appropriate special funds for that purpose, or program funding may depend on the implementing agency's making allocations from its general operation budget.

authority to the States to deal with groundwater quality problems;

- programs have not provided adequate and sustained funding for both development and implementation;
- programs have not been applicable to the hydrogeologic conditions in all States; and
- programs have had technical deficiencies.

These problems are related to the lack of Federal goals for groundwater protection and the failure of Federal programs to recognize both the interrelationships among all environmental media and the differences in State hydrogeologic conditions and institutional arrangements.

The States generally want Federal assistance in the form of funding, technical assistance, research and development, information management, administrative improvements, and policy development. Different States want different combinations of these kinds of assistance and would like assistance directed toward detection, correction, prevention, standards, or, more generally, improvement of State capabilities to handle contamination.

STATE PERCEPTIONS ABOUT GROUNDWATER CONTAMINATION PROBLEMS

Incidents of groundwater contamination have been identified in all 50 States (USGS, 1984), but perceptions about what constitutes a problem vary. For example, some States consider small areas of contamination or several incidents of contamination a statewide problem; others do not. The extent to which an isolated site-specific problem is of statewide concern is partly a function of the availability of alternative high-quality water supplies, the number of further incidents expected from various sources of contamination, and the capability of a State to detect and correct contamination from existing sources and to prevent contamination from new sources.

Several States commented on the future of groundwater protection. Some are pessimistic about controlling contamination, given the complexity of the problems and the politics and emotions involved. Other States are optimistic that contamination will be controlled *if* they are able to establish and/or implement programs to: 1) prevent groundwater quality degradation from a variety of sources; 2) obtain a better understanding of hydrogeology, sources,

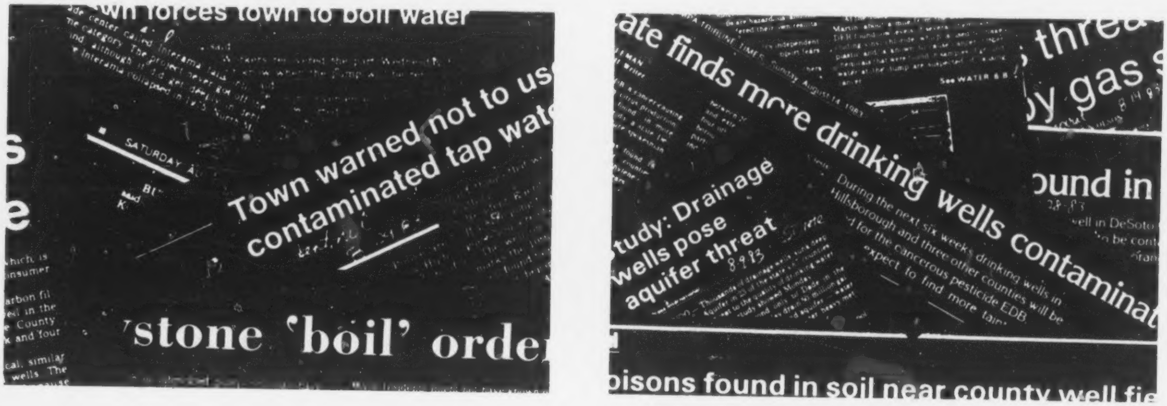
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Photo credits: State of Florida Department of Environmental Regulation

Contaminated groundwater has been detected in every State.

and groundwater quality; and 3) detect and correct contamination from existing sources.

Regardless of their perceptions of contamination problems, **all the States are working to improve their capabilities for protecting groundwater quality.** Overall, the States are devoting more attention to preventing contamination than to detecting or correcting it. This pattern is consistent with State comments on present and future priorities. Most States give highest priority to prevention.

OVERVIEW OF STATE ACTIVITIES TO PROTECT GROUNDWATER FROM CONTAMINATION

Historical Perspective

State efforts regarding contamination have been changing rapidly in the past few years. **The number of States working to address particular sources has increased substantially in the past 2 years.** Some States that have only recently recognized particular sources as problems (e.g., underground storage tanks) are beginning to address them. Figure 1 compares the number of States with programs *either* to detect, correct, or prevent groundwater contamination from selected sources in 1981 with the number in 1983. Information in the figure does not imply that all types of facilities and activities for any given source are included, that the same facilities and activities are covered consistently from State to State, or that details of programs for sources have remained the same over time.

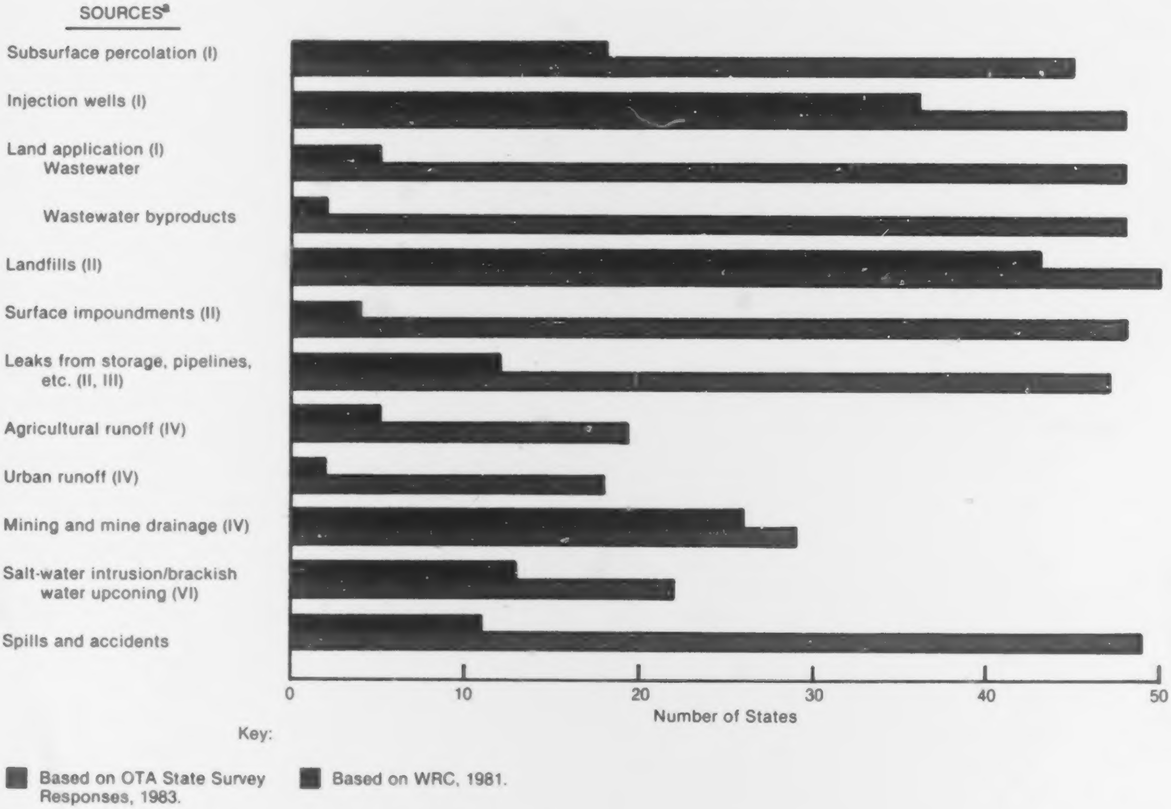
As discussed in chapter 3, the Federal Government has some type of program for nearly all these sources. The extent to which State activities are a response to Federal initiatives is not evident from available information. However, some State requirements are more stringent than available Federal guidance for some sources; other States are constrained from addressing certain sources by a lack of Federal initiatives. Further, some States commented that they can more easily address contamination from sources for which there is a Federal mandate.

Current State Programs

The OTA State survey asked the States whether they had programs to detect, correct, or prevent contamination from various sources. Figure 2 shows the number of States with *no* program to detect, correct, or prevent contamination from various sources. The fact that a State program is directed at a particular source does not necessarily imply that all aspects of contamination from that source are being addressed. A program may be limited to preventing further contamination from a particular source rather than focusing on detecting and/or correcting existing contamination. In addition, State programs may deal only with a subset of facilities and activities of any particular source type.

Two major points are apparent from figure 2: 1) **some sources of groundwater contamination are receiving attention from more States than others.** In general, sources in OTA Category I (sources designed to discharge substances) and Category II (sources designed to store, treat, and/or dispose of substances) are receiving the attention of more States than sources in Category IV (sources that discharge substances as a consequence of other planned activities); and 2) **not all States are addressing all potential sources.** The reasons given were: 1) the source is not commonly found or does not occur in the State; or 2) no problems with the source have been encountered. With respect to the first reason, sources that are most commonly found in particular regions include de-icing salts (northern States), salt-water intrusion/brackish water upconing (coastal and western States), and irrigation return flow (western agricultural lands). With respect to the reason that problems have not yet been found, it is possible that some problems will not be recognized until they are looked for. This point is especially true for the groundwater contaminants that are often not directly observable by taste, odor, color, or acute illness.

Figure 1.—Number of States With Programs to Detect, Correct, or Prevent Groundwater Contamination From Selected Sources in 1981 and 1983



[a] The sources included are those listed on both the OTA and WRC surveys. Roman numerals refer to OTA source categories (see table 5). See also the footnotes to fig. 2 for a description of the sources included.

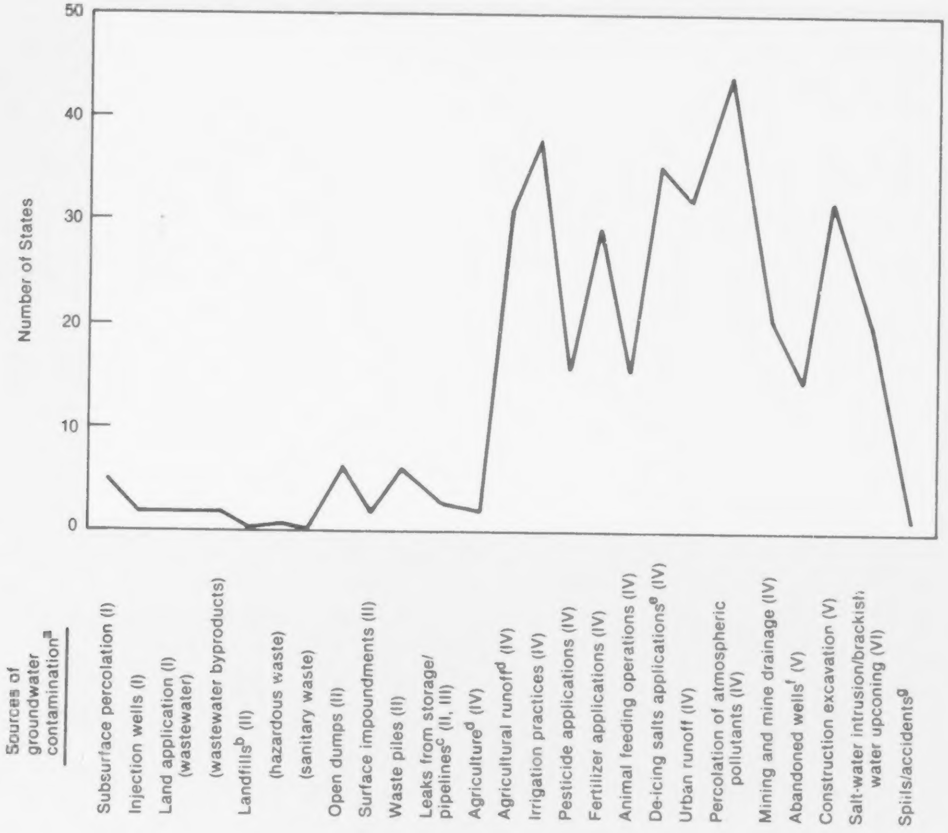
SOURCE: Water Resources Council (WRC), 1981; and the Office of Technology Assessment.

STATE EFFORTS TO IMPROVE CAPABILITIES TO DEAL WITH GROUNDWATER CONTAMINATION

States are undertaking a variety of activities to improve their capabilities to deal with groundwater contamination and are developing institutional frameworks to support their efforts. In this section, information provided in State survey responses about these activities is described. It demonstrates the general points which follow:

- The States are approaching the need to improve their efforts in many different ways.
- Most activity to improve capabilities is at an early stage of development. Training staff and developing their capabilities, detecting contamination, collecting data on particular sources or aquifers, and developing management strategies and programs are among the most commonly reported activities.
- All potential sources of contamination, as identified by OTA's study, are not being considered by all the States.

Figure 2.—OTA State Survey Responses: Number of States With No Programs To Detect, Correct, or Prevent Groundwater Contamination From Selected Sources



[a] The sources included are those listed on the OTA survey. Roman numerals refer to OTA source categories (see table 5).

[b] **Landfills.** Some States did not specify whether programs were for hazardous or sanitary landfills. Thus information on the number of States without hazardous or sanitary landfill programs is uncertain. However, one State explicitly noted that it did not have any programs for hazardous waste landfills. All States have some kind of landfill program.

[c] **Leaks from storage/pipelines.** The States were not specifically asked about storage tanks and containers (category II) and pipelines and materials transport and transfer operations (category III). These sources are combined into the general category of leaks from storage/pipelines about which the States were questioned.

More specific information on the status of State programs to address leakage of underground storage of petroleum products is available from (API, 1983b). State and local governments have been regulating underground storage at an increasing rate over the last several years.

Provisions of State underground leak laws are variable and may include one or more of the following basic elements: coverage of new or existing tanks; equipment or installation requirements exceeding those of the National Fire Protection Association or the Uniform Fire Code; secondary containment; replacement; inventory control; testing, monitoring; or abandonment provisions. Of the 18 States that have enacted statewide regulations, five States' programs include monitoring requirements, and two States had proposed monitoring requirements as of June 1983.

The Congressional Research Service (Feliciano, 1984) indicates that few State laws or regulations are directed toward prevention of leakage and groundwater contamination by underground storage tanks. And in several cases, the laws or regulations refer mainly to the need for preventing fire or explosion hazards caused by tank contents.

[d] **Agriculture and agricultural runoff.** Some States referenced general programs for agriculture and agricultural runoff rather than reporting on programs for irrigation practices, pesticide and fertilizer applications, and animal feeding operations.

[e] **De-icing salts.** The States were not asked to distinguish between the application of de-icing salts (IV) and the stockpiling of de-icing salts (II).

[f] **Abandoned wells.** The States were not asked to distinguish among the various types of production and other wells (V). Improper abandonment of any type of well can result in groundwater contamination.

[g] **Spills and accidents.** These have not been classified in a particular source category in OTA's assessment because a spill or accident can result in groundwater contamination from almost any type of source (e.g., rupture of storage tanks, spill in transport, and flooding of a surface impoundment) due to operational or management problems.

SOURCE: Office of Technology Assessment.

As shown in table 16, the highest number of States are working to improve staff capabilities, undertaking special studies, and improving coordination among programs. A large number of States is also involved in public education, facility development, and agency reorganization. Many States commented that their efforts—especially as related to staff development and training, public education, and facility development—were limited by insufficient funding. There is a wide variety of State activities, as shown in tables 17 and 18 and discussed below.

Staff Development and Training. Forty-five States reported staff development and training activities to improve their capabilities. Twenty-two States provided examples of activities, which can be classified as: classes and conferences (e.g, short courses, hands-on training, workshops, seminars, and safety training); benefits (e.g., improved salary structures, career ladders, continuing education funding, and management programs); and additional staff. Some States are engaging in more than one type of activity.

Special Studies. Forty-three States reported conducting special studies to improve their capabilities. All but two of these States provided examples of their studies, which cover five major areas: detection, sources and/or contaminants, aquifer characteristics, groundwater management and protection strategy development, and regulatory program development. The number of States reporting each type of activity and examples of their studies are presented in table 17. Some detail is provided about the types of sources being studied in table 18. Sources that discharge substances as a consequence of other planned activities (Category IV) are receiving the most attention.

Table 16.—OTA State Survey Responses: State Activities To Improve Capabilities To Deal With Groundwater Contamination

Number of States	Activity
45	Staff development and training
43	Special studies
42	Coordination programs
36	Public education
29	Facility development
24	Agency reorganization
10	Other

SOURCE: Office of Technology Assessment.

Coordination Programs. Forty-two States reported special coordination programs. All but two of these States provided examples of their coordination activities, which may be classified as: interagency coordination (e.g., with Federal agencies, among State agencies, and with regional agencies); program coordination; and other activities (e.g., formation of special groundwater committees, designation of special staff for coordination, management program strategy development, written agreements, and data base improvements). The most commonly reported activity was interagency coordination. Of the eight States noting coordination with Federal agencies, seven specified the agencies; the U.S. Geological Survey (USGS) was listed by all seven.

Forty-two States also reported benefitting from information provided by other States. Most information exchange among States occurs informally through: personal contacts (e.g., direct inquiry, visits, and informal discussions); attendance at events (e.g., conferences, seminars, special training sessions, and workshops); written materials (e.g., publications, newsletters, rules, regulations, and guidelines); associations (e.g., Association of State and Interstate Water Pollution Control Administrators, National Governors' Association, and interstate commissions); and contact with consultants and experts. Contact through Federal agencies (e.g., Environmental Protection Agency and USGS) was reported by relatively few States.

Table 19 summarizes major categories of information that the States want from each other. They are **primarily interested in learning about programs—types of approaches, successes, and failures—rather than about the details of individual sites.**

Thirty-two States reported a need to change some of their own practices to facilitate the exchange of information among States. Two types of changes were reported by the majority of States: 1) *improving data management*, such as by establishing an information clearinghouse, and 2) *preparing reports on State experiences*. Several States expressed interest in sharing their experiences through a centralized, national data base, recognizing that much of the information would have to be keyed to specific hydrogeologic conditions. Several States also noted that to write, print, and distribute reports

Table 17.—OTA State Survey Responses: Examples of Special Studies To Improve State Capabilities To Deal With Groundwater Contamination

Type of study	Number of:		Examples
	States	Studies	
A. Detection studies	24	33	
Problem areas	18	25	Coal mining area studies—UT; TCE studies—AZ.
Program development	5	5	Groundwater quality monitoring assessment—PA; Study of techniques for detection of pollutants—CT.
Source-related	3	5	Monitoring coal-fired electric generating plant sludge and ash pits, selected municipal lagoons, and selected oil and gas drilling and production facilities—ND.
Use-related	1	1	Investigating water quality at non-municipal public supply wells—AR.
B. Source and contaminant studies	19	34	
Assessments/inventories	13	16	Surface impoundment assessment and injection well inventories—AL; Statewide toxic substances assessment—NM; behavior of organic contaminants in groundwater—FL; pesticide studies—CA, WI.
Program development	6	7	Bulk storage program development—NY; rules needed for drilling oil and gas in hydrogen sulfide areas—OK; irrigation disposal well alternatives study—ID; Statewide assessment of magnitude of groundwater contamination—MI.
Impacts	6	8	Coal mining impact studies—UT; effects of salt-water disposal associated with oil field activities—MS; impact of pesticides on groundwater—FL, AZ, HI.
C. Aquifer studies	17	21	
Baseline data	14	16	Near-surface permeability—FL; recharge area maps—WV; hydrogeologic studies—GA, DE, IL, KY, NE, NJ, SC, SD.
Modeling studies	2	2	Solute transport studies—MS.
Contamination potential	2	3	Potential for contamination of shallow acquifers from land disposal of municipal wastes—IL.
D. Groundwater management protection strategy	12	20	
Program development	10	14	Prevention strategies for particular region—WA, NY; statewide management/protection strategy—AR, MI, NE, NY, ND, OK.
Contamination response	4	4	Point/non-point tradeoff project—NY; evaluate aquifer restoration/cleanup schemes—MA; incident response—NY, VT; Hydrogeologic Investigation Team—NH.
Staff development	1	1	Staff evaluations—DE.
Data management improvement	1	1	Groundwater management information system project—NY.
E. Regulatory program development	5	5	
Standard development	3	3	Develop standards for hazardous chemicals in groundwater—FL; develop and adopt groundwater quality standards—OR.
Enforcement	2	2	Coordinated UIC program—AR; permittee or responsibility party studies—DE.

SOURCE: Office of Technology Assessment.

Table 18.—OTA State Survey Responses: Distribution of State Special Studies Among Source Categories

Sources	Total number of studies	Assessments/ inventories	Program development	Impacts
Category I	5	4	1	—
Category II[a]	4	3	1	—
Category II[b]	2	—	2	—
Category III	—	—	—	—
Category IV	10	—	2	8
Category V	1	1	—	—
Category VI	—	—	—	—
Total[c]	22	8	6	8

[a] Waste.
[b] Non-waste.
[c] Note that the totals do not add up to the totals in table 17 because some of the contaminant-related studies indicated in that table (sources and contaminant studies) are not linked to specific source categories.
SOURCE: Office of Technology Assessment.

Table 19.—OTA State Survey Responses: Types of Useful Information From Other States

Information	Number of States[a]	Major topics of interest
Corrective	35	Experience with techniques; case histories; cleanup standards.
Detection activities	28	Experience with techniques; case histories; behavior of specific contaminants in particular hydrogeologic environments; monitoring programs.
Prevention activities	14	Experience with techniques, design criteria and siting requirements for some types of facilities; Best Management Practices.
Standards	14	General water quality standards; maximum contaminant levels; discharge standards; treatment or technology based standards.
Sources	11	Groundwater contamination problems associated with different sources.
Other	27	Groundwater quality management/protection strategies; risk assessment information; impacts of groundwater contamination; research results; legislation; interstate groundwater flow and quality; public education.

[a] Forty-eight States described the types of information that would be useful.
SOURCE: Office of Technology Assessment.

and studies on their experiences requires increased staff and support budgets.

Public Education. Thirty-six States reported public education activities, and 16 listed examples: written materials (e.g., pamphlets, magazine articles, and use of the news media) and personal contacts (e.g., workshops with consultants, seminars, and speaker bureaus). Some States noted that they have public information programs; the programs may be either general or targeted at particular sources or areas where groundwater contamination is of concern.

Facility Development. Twenty-nine States reported facility development activities, with 22 States listing examples. The most commonly reported activity is related to laboratory improvements (e.g., expansion of State water quality laboratories, certification and quality assurance checks on private laboratories, upgrading techniques, additional analysis of particular substances such as organic chemicals or radionuclides, and purchase of laboratory equipment). Other activities listed include improving computer capabilities, developing special waste disposal facilities (e.g., State hazardous waste facilities and agricultural chemical washing facilities), and establishing quality assurance programs.

Agency Reorganization. Twenty-four States reported some type of agency reorganization designed at least in part to improve their capabilities to deal with groundwater contamination. Twelve States gave examples, which may be categorized as: consolidating groundwater expertise in one group or establishing a special task force; creating a single agency for the environment or for water resources; and establishing a special agency or group for special projects or sites of contamination.

Other Activities. The "other" category listed by 10 States relates primarily to either general program development (e.g., specific laws, priorities, or standards for groundwater) or data collection (e.g., improved drilling capability and monitoring and inventory efforts).

STATE PERSPECTIVE ON FEDERAL PROGRAMS

In this section, two major themes are discussed: 1) whether selected Federal laws and programs have helped or hindered State efforts to protect groundwater quality, and 2) how States use Federal water quality standards and guidance for groundwater contaminants.

State Responses About Selected Federal Laws

In the State survey, the States were asked whether selected Federal laws and programs have been a help to them or hindrance. For the most part, Federal laws and programs have helped many States address contamination. Several States pointed out problems with some Federal programs. In general, States have different problems. They relate primarily to Federal programs that: shift problems with the quality of another environmental medium to groundwater; divert resources to activities other than groundwater; do not explicitly authorize consideration of groundwater; lack flexibility to address specific conditions in a State; create administrative problems for a State; do not fund activities mandated by the Federal Government; and have provisions that the States view as technically unsound or inappropriate.

Table 20 shows the number of States commenting positively and/or negatively about the laws and programs. When a State commented both positively *and* negatively, the comments may apply to a single section of a law or to different sections. The "no impact" comment has several possible meanings: 1) that the law or program does not apply to the State (e.g., the Bureau of Indian Affairs (BIA) is active only in States with Indian lands and the Coastal Zone Management Act (CZMA) applies only to States bordering seacoasts or the Great Lakes); 2) that respondents to the questionnaire were not familiar with the applicability of the law or program to groundwater issues (e.g., the National Bureau of Standards (NBS)); or 3) that the law or program has no bearing on the efforts of a particular State (e.g., Surface Mining Control and Reclamation Act (SMCRA) and CZMA). Note that the number of States commenting that a law or program has no impact on their efforts to deal with groundwater contamination is relatively large.

In the following discussion, information on the negative comments is presented in detail. These comments provide a basis for determining needed changes in existing laws and programs, or approaches to avoid in establishing new programs, to help the States with their groundwater contamination problems.

The positive comments, not discussed in detail here, indicate the types of Federal laws, programs, and services that the States view as helpful. In general, the positive comments include many of the points made by the States in their response to questions about how the Federal Government can best assist them (see the next major section, e.g., technical assistance, funding, research and development, and information management). Positive comments were also made for Federal programs that, for example, are flexible and can be tailored to individual State needs and conditions.

Table 20.—OTA State Survey Responses: Number of States Reporting Positive and/or Negative Effects of Selected Federal Laws and Programs on Efforts To Deal With Groundwater Contamination[a]

	State response			
	Positive	Negative	Both positive and negative	No impact
Laws				
CWA	33	2	12	3
SDWA	36	1	10	3
RCRA	33	2	10	5
CERCLA	31	0	4	15
TSCA	12	0	0	38
UMTRCA	7	0	2	41
FIFRA	11	1	1	37
CZMA	6	0	1	43
SMCRA	15	2	1	32
Programs				
SCS	26	2	1	21
ASCS	16	0	0	34
NBS	4	0	0	46
BIA	2	0	1	47
BLM	7	0	1	42
BuRec	8	0	0	42
USGS	43	0	1	6
WRDA	14	0	1	35

[a] See text and ch. 3 for abbreviations.

SOURCE: Office of Technology Assessment.

Federal laws and programs that have influenced the most States include: the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and programs of USGS. Most States view favorably the contribution these laws and programs have made to their handling of contamination programs. But, with the exception of USGS programs and CERCLA, a relatively large number of States noted that these Federal programs have also had negative (or both positive and negative) effects on their efforts.

It is important to recognize that **although one State may view a particular section of a law as limited in its application to groundwater, another State may be using that same provision very effectively**. Such discrepancies may reflect differences among States' groundwater problems as well as institutional differences (e.g., authority and priorities) which affect the use of a State's resources. Negative aspects of these laws and programs mentioned by the States are described below, with emphasis on the laws receiving the most negative comments (i.e., CWA, SDWA, and RCRA).

Clean Water Act. The States were asked to comment on Sections 104 (Research, Investigation, Training, and Information); 106 (Grants for Pollution Control); 201 (Grants for Construction of Treatment Works); 205j (Grants for Water Quality Management Planning); 208 (Areawide Waste Treatment); 303 (Water Quality Standards and Implementation Plans); and 402 (National Pollutant Discharge Elimination System, NPDES). Fourteen States made negative comments about the various sections. Two major issues were raised about how the act has hindered State efforts to deal with groundwater contamination:

1. Ten States noted that the act has **promoted surface water quality protection efforts to the detriment of groundwater quality** (e.g., land disposal practices, increased wastewater treatment, and point source discharges in normally dry streambeds) and has **diverted resources away from groundwater issues.**
2. One State noted that the **lack of explicit authority in the law to address discharges to groundwater** has prevented the State from doing so.

It should be noted that many States are actively using their discharge elimination permit systems to regulate discharges to groundwater (20 States commented only positively on Section 402).

Safe Drinking Water Act. The States were asked to comment on the following portions of this law: Part B—Section 1412 (National Drinking Water Regulations); Part C—the Underground Injection Control Program and the Sole Source Aquifer Program; and Part E—Sections 1442 (Research, Technical Assistance, Information, and Training of Personnel) and 1443 (Grants for State Programs). The negative comments from 11 States about one or more of these provisions raised two major issues:

1. Six States noted that the provisions of the Sole Source Aquifer Program and the Underground Injection Control Program were **not applicable to or were of little value for conditions in their States.**
2. Six States noted **administrative problems** with implementation of the Underground Injection Program and Sections 1442 and 1443.

Resource Conservation and Recovery Act. The States were asked to comment on Subtitles C (Hazardous Waste Management) and D (State or Regional Solid Waste Plans) of the act. Twelve States made negative comments about one or both provisions, with three major points of concern:

1. Eight States cited **problems with administration or implementation of program requirements** (e.g., difficulties with requirements for authorization of State programs or conflicts between Federal requirements and ongoing State programs; difficulties in dealing with EPA staff and coordinating with other EPA programs; inflexibility of certain rules; and lack of Federal support for enforcement of Subtitle D).
2. Five States noted **funding problems,** particularly for Subtitle D, but also for monitoring, laboratory facilities, and staff to implement Subtitle C.
3. Three States cited **technical shortcomings** within the law: the emphasis on land disposal, mandated use of liners, and inadequate performance standards that, according to one State, hinder proper disposal; the lack of information about the adverse effects of various concentrations of contaminants; the omission of some known toxic or carcinogenic chemicals from RCRA's hazardous waste list; and questions about the applicability of statistical methods used to evaluate concentrations of synthetic chemicals.

Other Laws and Programs. The negative comments made by a relatively few States about other Federal laws and programs generally relate to the same kinds of problems and concerns discussed above for the Clean Water Act, the Safe Drinking Water Act, and the Resource Conservation and Recovery Act.

That the law or program **shifts surface water quality problems to groundwater** was mentioned by three States with respect to the Soil Conservation Service, by one State with respect to studies supported by its Water Resources Research Institute, and by one State with respect to the Bureau of Land Management and the Bureau of Indian Affairs.

The lack of explicit authority to deal with groundwater quality problems has been a problem for one State with respect to the Surface Mining Control and Reclamation Act (SMCRA). Three other States noted that SMCRA has little impact on groundwater quality.

Administrative problems with the Uranium Mill Tailings Radiation Control Act (UMTRCA), noted by two States, relate to coordination between State and Federal agencies; with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), noted by three States, relate to problems with coordination and the slow rate of progress in program implementation; with SMCRA, noted by one State, relate to retaining State primacy; and with the Coastal Zone Management Act, noted by one State, relate to coordination problems among State agencies.

Funding problems with the USGS Cooperative Program were indicated by one State. The State was unable to participate in the Program because of the cash payments required for matching funds. One State mentioned the lack of funding to comply with Federal requirements under CERCLA to evaluate sites.

Technical shortcomings were noted by two States with respect to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); some registered pesticides have contaminated groundwater.

State Use of Federal Guidance on Quality Standards for Groundwater

Water quality standards provide a baseline for detection, correction, and prevention activities. The States apply standards to groundwater through their drinking water quality programs and/or groundwater quality programs.

As mentioned in chapter 3, the Federal statutes require the establishment of quality standards for drinking water and surface water. The Federal Government establishes minimum standards for selected substances in drinking water and provides guidance for additional substances in drinking water and surface water. Although the Federal Government does not require the States to set quality standards for groundwater, many States have done so, especially in the past 2 years, as shown in table 21. States have either established explicit authority for groundwater quality standards or have used their general authority over water quality (often based on Federal mandates to control surface water pollution) to address groundwater. Some States have not developed groundwater quality standards in the absence of explicit Federal guidance.

Also shown in table 21 are the types of State groundwater quality standards—i.e., whether standards are numerical, narrative, or both. Numerical standards specify concentration limits (e.g., parts per million of a substance). Narrative standards describe limits but do not specify concentrations (e.g., a non-degradation standard requiring that concentrations be at or below natural background levels) or even necessarily individual contaminants (e.g., a standard prohibiting the discharge of toxic, carcinogenic, teratogenic, or mutagenic substances into groundwater). Numerical standards are generally preferable to narrative standards because the substances that are covered and the concentrations that are acceptable are clearly stated. Because of difficulties in obtaining toxicological and risk-related information (discussed in ch. 2 and app. A.1), there are many problems in developing numerical water quality standards.

State standards are based on available literature; the States have not conducted their own research to determine toxicological, risk, and impact information. Some standards are based on the detection limits of instrumentation, for practical purposes, rather than on the appraisal of risks associated with different concentrations of individual substances.

Major conclusions about State water quality standards applied to groundwater, compared with available Federal water quality standards and guidelines, are discussed below.

Federal drinking water standards and guidance on acceptable concentrations of substances in water are not adequate for State needs. When Federal standards or guidance are available, the States often do not rely on them. Although it is not required by Federal law, most States have developed or are developing groundwater quality standards. Some States have established drinking water standards for substances in addition to, and/or applied more stringent standards to, those substances cov-

Table 21.—Types of State Groundwater Quality Standards Programs in 1981 and 1983

	Types of standards/number of States					
	1983					1981
State groundwater quality standards programs	Numerical	Narrative	Both	Not specified	Total	Total
Programs exist specific to groundwater	6	3	10	1	20	8
Programs exist based on general water quality standards that apply to both surface water and groundwater	2	2	1	6	11	1
Developing programs specific to groundwater	1	4	1	6	12	9
No program development	—	—	—	—	7	32

SOURCE: Office of Technology Assessment; American Petroleum Institute (API), 1983; and WRC, 1981.

ered by Federal regulations. State standards include numerical limits for many substances for which the Federal Government has provided no guidance.

The standards States apply to groundwater are extremely diverse. They have developed standards for different substances, and when different States have standards for the same substance, the values are usually not the same. It is not clear, however, how different standards affect the level of groundwater quality protection, given the varying behavior of contaminants in different hydrogeologic environments and the many uses of groundwater.

Appendix C.3, a table on Federal and State water quality standards, indicates the range of drinking water and groundwater quality standards established by the States, the States with these standards, the standards established by the Federal National Interim Primary and Secondary Drinking Water Regulations, and Federal guidance provided by Health Advisories and Ambient Water Quality Criteria. A summary of comments, drawn from appendix C.3, follows:

- States have developed water quality standards for numerous substances for which the Federal Government has not established standards or provided guidance. The States have established drinking water or groundwater quality standards or other indicators of quality for over 150 substances. The Federal Government has established standards or provided guidance for developing water quality standards for less than half of this number. The Federal Government has provided guidelines for fewer than 20 substances for which no State has standards.
- Apart from the substances covered by the National Interim Primary Drinking Water Regulations, few States have developed standards for the same substances (i.e., different States have generally developed standards for different substances).
- Even when States have standards for the same substances, the standards are usually not the same.
- State water quality standards differ in stringency from Federal standards or guidelines for the same substances. In general, State *drinking water standards* are more stringent than National Secondary Drinking Water Regulations and Ambient Water Quality Criteria. In general, State *groundwater quality standards* are also more stringent than Federal guidelines, but there are substantial numbers of substances for which the State groundwater quality standards are less stringent than Ambient Water Quality Criteria.
- Overall, the States have established groundwater quality standards for many more substances than they have established drinking water standards;[3] this may reflect the States' orientation to the prevention of groundwater contamination. The substances for which a State has established groundwater quality standards are usually different than the ones for which it has established drinking water standards. If a State has established drinking water standards and groundwater quality standards for the same substance, the groundwater quality standard is usually more stringent than the drinking water standard.

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[3] In New York, the State with groundwater quality standards for the highest number of substances, groundwater quality standards serve as guidelines for drinking water quality. Reconnaissance studies conducted by the State are used to identify water supplies that have the potential to be contaminated from these substances. More detailed investigations are undertaken if a potential problem is identified. The State has found that water suppliers are responsive to the use of guidelines and has not felt the need to establish formal regulations (Markusen, 1984).

STATE STRENGTHS AND PROBLEMS IN PROGRAMS TO DEAL WITH GROUNDWATER CONTAMINATION AND DESIRED FEDERAL ASSISTANCE

In response to survey questions about strengths and problems in State groundwater protection programs (e.g., program weaknesses, needed changes, and limiting factors) and how the Federal Government can be of most assistance, the States brought up a number of issues related to six topics: 1) sources of contamination, 2) general capabilities to deal with contamination, 3) standards for groundwater quality, 4) detection, 5) correction, and/or 6) prevention. Table 22 summarizes the State responses. Individual responses are presented in appendix C.4; and examples of issues for which each State appears to be particularly articulate are presented in appendix C.5. Major findings, presented below, are followed by details on each topic:

- Because the questions were basically open-ended (i.e., the States were not asked directly about strengths, problems, and the desire for Federal assistance with respect to detection, correction, and prevention), table 22 reflects the issues that questionnaire respondents voluntarily raised, perhaps feeling they were of the greatest concern to their groundwater programs. The fact that a State did not comment about a particular issue does not necessarily reflect a lack of strengths, problems, or desire for Federal assistance with respect to that topic.
- The fact that the highest number of States commented about improving capabilities and detection probably reflects the **early stage of development of most State programs.** That these issues dominate many States' concerns does not mean that they do not need assistance in other areas.
- Many States did not highlight any strengths, **all the States noted problems,** and nearly all want some change in Federal assistance efforts.
- Comments on **strengths relate primarily to the existence of institutional mechanisms** (e.g., authority and program regulations) to address various components of the problems in a State. Comments on **problems relate primarily to resources (e.g., financial, staff, and information) or authority.** Comments on desired Federal assistance address six major categories: 1) funding, 2) technical assistance, 3) research and development, 4) new policy development, 5) information management, and 6) administrative improvements. Funding, technical assistance, and R&D were suggested by the highest number of States. Six States mentioned the need for a national policy on protection of groundwater in order to overcome State program constraints in handling groundwater contamination; at least 14 other States want

Table 22.—OTA State Survey Responses: Strengths and Problems in Programs To Deal With Groundwater Contamination and Desired Federal Assistance

	Number of States			
Issues	Strengths	Problems	Desired Federal assistance	Total
Sources	22	20	—	33
Improving capabilities	12	48	41	50
Standards	3	19	19	28
Detection	15	38	29	46
Correction	6	19	23	35
Prevention	0	12	10	18
Total States	38	50	48	50

SOURCE: Office of Technology Assessment.

Federal funds for development of State policies and programs.

- The States do not want Federal assistance on all the problems that they identified. In particular, **they do not desire Federal assistance with problems related to water rights.**
- Survey responses reveal a great deal of variability. **One State's strengths may be another's problems.** Different States highlight problems with different sources and different aspects of programs for improving capabilities, standards, detection, correction, and prevention. Some States are concerned about establishing authority, and others about either developing or implementing programs. A State may have different needs for different sources or for detection, correction, or prevention. In addition, the States seek different kinds of Federal assistance.

Sources

Strengths and Problems

Thirty-three States commented on the adequacy of their authority to deal with sources of contamination. Some States listed *either* strengths or *problems* with respect to authority for sources, and some listed *both*. When both strengths and problems were noted, they relate to different categories of sources, different sources within a single category, or different characteristics of facilities or sites of a particular source type. Other comments on sources are related to strengths and problems with detection, correction, prevention, or improving capabilities. They are discussed in that context below.

Although the States did not use the same terminology, apparently many sources for which some States reported having adequate authority are the same sources for which other States reported inadequate authority. These responses highlight the fact that the States have different capabilities for dealing with different sources of contamination and may indicate that individual States are most concerned about different sources of contamination. In addition, relatively few States commented on the adequacy of their authority for specific sources. However, a relatively large number of States commented on the inadequacy of their authority to deal with agriculturally related sources (including agricultural wastes, non-point source control, and pesticide and fertilizer use) and underground storage tanks. No States commented specifically on having adequate authority to deal with these sources.

A State may have adequate authority with regard to some facilities associated with a particular source but not regarding others. Table 23 lists characteristics of sources for which States reported their relative success in establishing and/or implementing programs to control groundwater contamination. The relative success of controlling contamination may reflect the ease with which States are able to acquire authority to regulate different types of operations (which may in turn relate to public support, available resources, number of facilities, and

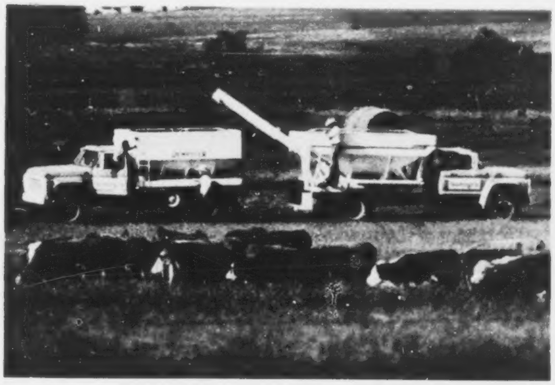

Photo credits: Office of Technology Assessment (left) and State of Florida Department of Environmental Regulation (right)

Many States lack adequate authority to deal with agriculturally related activities that are potential sources of groundwater contamination including fertilizer applications and animal feedlot operations.

Table 23.—OTA State Survey Responses: Types of Sources for Which States Experience Variations in Their Ability To Deal Effectively With Groundwater Contamination

More success	Less success
New facilities	Old facilities
Active sites	Inactive sites
Large operators, facilities, sites	Small operators, facilities, sites
Regulation federally mandated	Regulation not federally mandated
Concentrated sources	Widespread sources
Nonagriculture	Agriculture
Point sources	Non-point sources
Industrial wastes	Household wastes

SOURCE: Office of Technology Assessment.

other factors). Success may also reflect the kinds of options that are available for controlling contamination from different sources (e.g., it may be easier and less expensive to design new facilities than to retrofit old ones to prevent contamination).

Federal Assistance

Sources of contamination were not mentioned specifically when the States listed desired Federal assistance. Rather, desired assistance related to improving capabilities, standards, detection, correction, and prevention, as described in the following sections.

Improving Capabilities

Strengths and Problems

All of the States commented on their strengths, problems, and/or desire for Federal assistance to improve their handling of contamination. Comments on strengths relate primarily to institutional mechanisms that provide flexibility for responding to newly recognized problems (e.g., coordination among State programs, staff training opportunities, and legislative support). Other strengths include availability of information on aquifer characteristics as an aid to decisionmaking.

Comments on problems relate primarily to having sufficient resources and support to establish or implement institutional mechanisms. Almost all of the States are concerned with having sufficient funds and staff. Funding problems were reported by the highest number of States. With staff, the problems relate to having, attracting, and retaining sufficient numbers of adequately trained personnel.

The States also noted that a number of changes are required in their programs. Several States recognize problems with their institutional framework, including lack of authority to deal with contamination, and inability to develop and implement a coordinated strategy (e.g., because of factors related to regulations and their enforcement). Resolution of these institutional problems is complicated in some States by the lack of support of various interest groups, policy conflicts or coordination problems among State agencies and between State and Federal programs, and the low priority of groundwater relative to surface water.

Federal Assistance

Forty-one States expressed a desire for Federal assistance to improve their capabilities—apart from Federal assistance related to standards, detection, correction, and prevention. Desired types of Federal assistance to improve capabilities, indicated by the highest number of States, include: general technical assistance for groundwater quality programs; funding for development of groundwater policies and programs, State research and development, and staff training; and Federal activities related to information management and information/technology transfer. Suggested improvements to Federal regulatory programs include more flexible regulations to meet individual States' needs, coordination among Federal laws and among Federal and State agencies, and adequate funding for federally mandated programs.

Standards

Strengths and Problems

Twenty-eight States commented about their strengths and problems with quality standards for groundwater or drinking water and desire Federal assistance in this area. Strengths relate primarily to the existence of standards for groundwater quality. The most frequently reported problems are the lack of groundwater quality standards in general and the lack of numerical standards or toxicological or risk information for particular substances (e.g., volatile or synthetic organics and radiological substances).

Federal Assistance

Nineteen States reported a desire for Federal assistance related to quality standards (two of them also commented on strengths in their own efforts). Research and development was most frequently cited (e.g., information on toxicology, impacts, and risk assessment). Other suggestions are for technical assistance and additional Federal drinking water standards.

Detection

Strengths and Problems

Forty-six States commented about the strengths and problems with their efforts, and about their desire for Federal assistance, to detect contamination. Strengths relate primarily to institutional resources and mechanisms (e.g., staff expertise and coordination among State agencies) to detect contamination, at least from some sources. More States noted strengths with respect to their detection efforts than they did with respect to any other category of activity related to dealing with contamination.

Nearly all the States commenting on the strengths of their detection programs also noted problems. Problems relate primarily to institutional concerns, particularly funding and other resource (e.g., staff) constraints that prevent a State from obtaining data on groundwater contamination. Not having the authority to obtain data on particular sources is a problem for many States. Many noted the need to modify and increase monitoring activities, although they differed on focus—whether the emphasis should be sources of contamination, aquifer characteristics, or ambient quality.

Federal Assistance

Twenty-nine States expressed a desire for Federal assistance specifically related to detection. Funding for data collection was the most commonly reported. Research and development for monitoring and technical assistance for hydrogeologic analysis and interpretation were also listed. In addition, funding, technical support, and R&D for laboratory analysis were noted.

Correction

Strengths and Problems

Thirty-five States commented about strengths and problems and their desire for Federal assistance with corrective action. In general, their strengths relate to the existence of institutional mechanisms (e.g., authority, funding, and priority ranking systems) to undertake corrective action for at least some sources. Their problems relate primarily to insufficient funding and other resources (e.g., staff). Other problems relate to inadequate institutional mechanisms (e.g., authority, including water rights, coordination, and enforcement) and to the lack of technology for correcting contamination in some environments (e.g., karst).

Federal Assistance

Twenty-three States expressed a desire for Federal assistance related specifically to corrective action, 12 of them noting neither strengths nor problems in this area. The highest number of States specified technical assistance (e.g., to implement corrective action, to train staff on safety and on the use of corrective action techniques, and to deal with the public when groundwater contamination is discovered); improvements through research and development (e.g., low-cost corrective action techniques for treating specific contaminants, for particular sources like on-site waste disposal or oil field wastes, or for aquifers in general; and cleanup standards); and funding assistance (e.g., to deal with contamination in general, existing problems, large problems, and sources for which Federal funding is not available). Other areas cited by a few States include: Federal program administration (e.g., continued support or improvements to the Federal "Superfund" program); Federal policy development (e.g., establishing a national groundwater policy for prevention and correction); and development of an information clearinghouse related to experience with corrective action.

Prevention

Strengths and Problems

Eighteen States commented about problems or desired Federal assistance for prevention of contamination. No States commented specifically about strengths in their prevention programs.

Comments on problems were institutional in nature and relate either primarily to the absence of or deficiencies in some types of programs for prevention (e.g., classification systems, well-drilling standards, environmental impairment liability insurance, recharge area protection, and hazardous waste disposal facilities) or to the lack of resources to implement existing institutional mechanisms (e.g., funds for existing prevention programs to handle more potential sources of contamination). The technical adequacy of some prevention mechanisms was questioned by one State.

Federal Assistance

Ten States desire Federal assistance for prevention activities. Comments relate primarily to research and development activities (e.g., developing control technologies or Best Management Practices (BMPs) for additional sources or contaminants and determining which substances should never be discharged to groundwater) and to funding (e.g., to implement BMPs and federally mandated programs). Additional Federal assistance is also desired for information management (e.g., a clearinghouse for information on State approaches and regulations to prevent groundwater contamination) and for changes to existing Federal programs (e.g., change in the emphasis of RCRA from land disposal to recycling and chemical destruction of toxic materials and improvements in FIFRA pesticide registration requirements to increase success in identifying contamination potential prior to marketing).

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Hydrogeologic Investigations of Groundwater Contamination

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Chapter 5

Hydrogeologic Investigations of Groundwater Contamination

CHAPTER OVERVIEW

This chapter describes the current status of hydrogeologic investigations. The first section, *The Conduct of Hydrogeologic Investigations,* summarizes the general approach used for investigations, describes the two primary driving forces of investigations (i.e., site conditions and objectives), and discusses the design of investigations in terms of information requirements, techniques, and monitoring networks. (This section is based on GeoTrans, Inc., 1983a, unless otherwise indicated.) The second section, *Approaches for Minimizing Difficulties With Groundwater Contamination Investigations,* discusses reliability of data collection and interpretation.

The conclusions that follow are based on this information.

Hydrogeologic investigations play an integral role in understanding and evaluating groundwater contamination regardless of the policy objective (i.e., whether to detect, correct, or prevent contamination). The techniques for obtaining information on hydrogeologic conditions and groundwater quality are now generally available.

Because of the inherent difficulties in dealing with the subsurface (e.g., its inaccessibility to direct observation), there will always be some degree of uncertainty about contaminants—which substances are present and at what concentrations, where they are going, and how fast they are moving. The nature and degree of the uncertainty vary according to such factors as the hydrogeologic environment, types of contaminants, the number and history of the sources involved, and the type of techniques used. Under most circumstances, the uncertainties can be reduced, although not eliminated, to obtain reliable results. The uncertainties are most often reduced by combining complementary techniques and/or collecting increasingly detailed site information. These strategies, however, usually increase the costs of and/or time for an investigation. The impacts of uncertainties on decisionmaking can be minimized by making conservative assumptions and conducting sensitivity analyses.

Design and implementation of investigations are highly dependent both on site-specific conditions and on the specific objective to be achieved at a site (i.e., detection, correction, or prevention). The site- and objective-specific nature of groundwater contamination problems requires that investigations be tailored to each individual problem. It is thus impractical to standardize requirements for hydrogeologic investigations (e.g., with respect to the number or location of monitoring wells). The burden of performing reliable hydrogeologic investigations falls on those responsible for obtaining, interpreting, and applying results; and the required skilled personnel are in short supply.

Many techniques are available for analyzing contaminants once a groundwater sample has been obtained. Generally, the techniques *identify contaminants* and *quantify their concentrations,* but they also introduce a bias in terms of which of the contaminants present are detected. *Behavioral properties* of contaminants (e.g., mobility and toxicity), on the other hand, cannot be measured directly and thus must be deduced from indirect information, experience, and judgment. Understanding the behavior of contaminants is important for detection, correction, and prevention of problems.

THE CONDUCT OF HYDROGEOLOGIC INVESTIGATIONS

General Approach of Investigations

Hydrogeologic investigations are the process for collecting and analyzing information on the presence and behavior of contaminants in the subsurface. This knowledge is obtained primarily by collecting and analyzing data on the *hydrogeologic environment* (to ascertain the rate and direction of groundwater flow and help predict contaminant behavior) and on *groundwater quality* (to ascertain the presence and concentrations of contaminants). Investigations are simplified if information about the nature and location of *sources of contamination* is known and if information is available on the *properties of contaminants* likely to be found. Knowledge of contaminant properties is helpful, for example, in determining how fast contaminants move relative to groundwater flow or if they move independently of flow.

Hydrogeologic investigations usually involve the design and operation of a groundwater quality monitoring network to collect data on the behavior of contaminants in the subsurface in order to satisfy detection, correction, or prevention objectives.[1] For example, to detect contamination from a potential source, understanding the behavior of expected contaminants is required to determine where contamination is most likely to be found. To correct a problem, understanding contaminant behavior is necessary to determine the nature and extent of the problem and to predict responses to alternative corrective measures. To prevent contamination, understanding contaminant behavior is necessary to select, design, and evaluate preventive measures.

Key issues in the design of monitoring systems are: what information is required, what techniques are applicable for obtaining this information, what should be the number and location of measuring points, and how frequently should samples be collected. Answers to these questions depend on conditions at the site and the objectives to be achieved.

Hydrogeologic investigations of groundwater contamination problems rely on many of the same techniques (e.g., groundwater exploration, aquifer testing, geochemistry, and mathematical modeling of groundwater flow) developed in the past 60 years to evaluate groundwater resources for supply purposes. These hydrogeologic techniques were developed primarily to evaluate permeable and saturated geologic units (e.g., aquifers) covering extensive areas most often at the county or regional scale. For investigations of contamination, the scale is usually much smaller; and low permeability units, which can act as a barrier to contaminant migration, and the unsaturated zone, which can retain contaminants for long periods, can be very significant. Data that were historically collected and analyzed only in special research studies must be obtained routinely in investigations of contamination.

Many simplifying assumptions often used in groundwater supply investigations (e.g., that the vertical component of flow is not significant; that flow in fractured media can be approximated by an equivalent porous media; and that the unsaturated zone is of minor importance) are often not applicable in groundwater contamination investigations. As a result, the costs and time required for these hydrogeologic investigations are higher than those for water supply investigations. In addition, the investigation of contamination requires more precise well drilling and water quality sampling.

Site Conditions

There are inherent difficulties in obtaining information on an environment that not only is mostly inaccessible to direct observation but is also extremely variable in both space (i.e., the hydrogeology at a single site may be complex and non-uniform) **and time** (i.e., the rate and direction of groundwater flow and groundwater quality are not constant). Each site will have a unique combination of characteristics including:[2]

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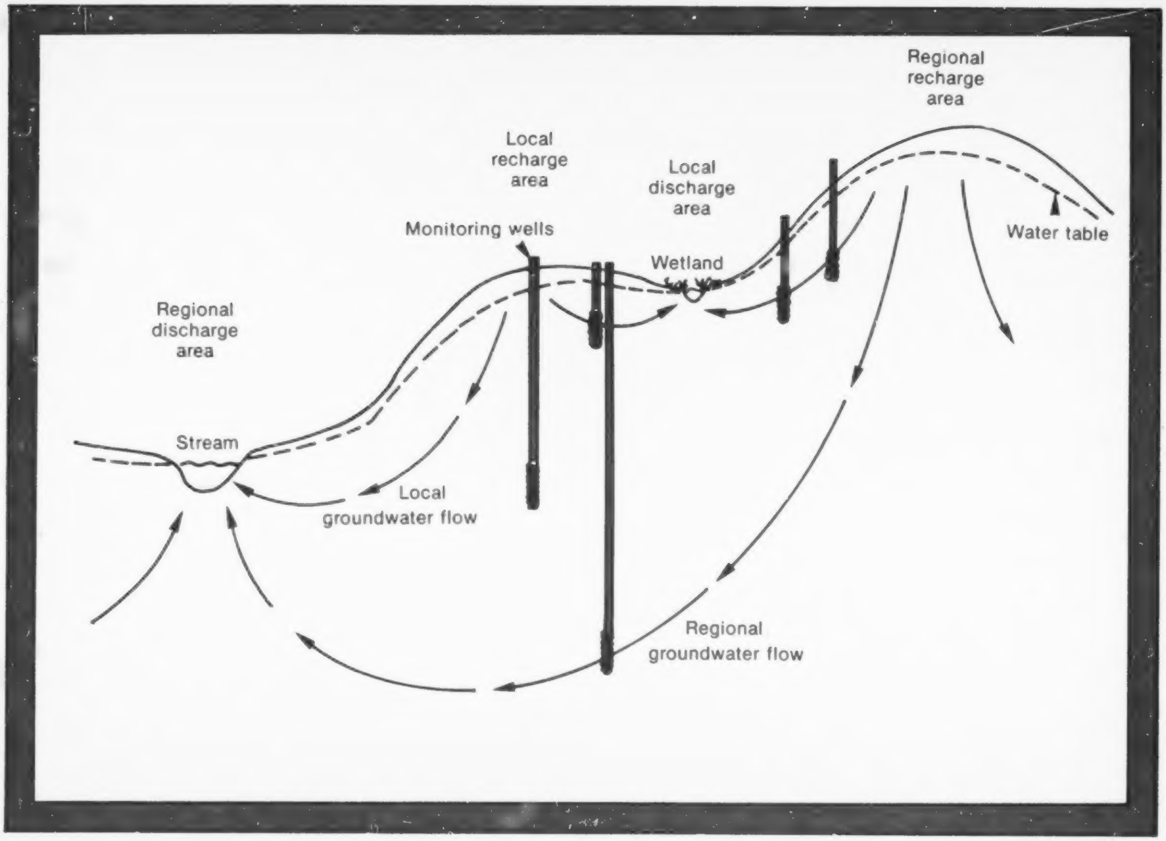
[1] For sample discussions of methodologies for hydrogeologic investigations, see Todd, et al., 1976; Wood, et al., 1984; and GeoTrans, Inc., 1983b.

[2] Listing is based on discussion by Keith, et al., 1982a.


Regional recharge area
Local recharge area
Local discharge area
Monitoring wells
Water table
Wetland
Regional discharge area
Stream
Local groundwater flow
Regional groundwater flow

Credit: Geraghty & Miller, 1983

Regional groundwater flow is of primary interest in evaluating the water supply potential of an aquifer; local groundwater flow is of primary concern in investigations of contamination.

- sources of contaminants (e.g., associated types of contaminants and release patterns);
- the hydrogeologic environment (e.g., topography, vegetation, climate, geology, surface and subsurface hydrology, unsaturated zone, and contaminant transport parameters); and
- groundwater use (e.g., effects of pumping rates and schedules on groundwater flow).

To have confidence that the interpretation of information in hydrogeologic investigations reflects actual conditions in the subsurface, some investigations require more detailed information than others on the hydrogeologic environment and groundwater quality. More detailed information is required at sites where: the hydrogeologic environment is very complex (e.g., heterogeneous or fractured aquifers v. uniform or simple aquifers), the contaminants present do not move with groundwater flow (e.g., the presence of immiscible v. miscible contaminants), and information is limited about which contaminants are present, contaminant properties, and sources and their contaminant release characteristics.

Objectives

The different purposes of hydrogeologic investigations—detection, correction, and prevention—are presented in table 24. As shown, the design and operation of a monitoring effort will vary according to the objective to be achieved, the steps to be taken to meet the objective, and the type of pro-

Table 24.—Elements of Groundwater Protection and Topics for Hydrogeologic Investigations

Detection	Correction	Prevention
Objectives		
Identify/quantify existing contamination	Characterize nature and extent of contamination	Identify potential for future contamination
Characterize nature and extent of contamination	Reduce/eliminate existing groundwater contamination	Hinder/prohibit contaminants from entering subsurface
Assess impacts	Assess/reduce/eliminate impacts of groundwater contamination	Assess/reduce/eliminate impacts of future contamination
Steps in meeting objectives		
Evaluate detection options—assess their applicability and potential impacts	Evaluate both technology- and management-based corrective action options — assess their applicability and potential impacts	Evaluate preventive action measures — assess their applicability and potential impacts
Select detection measures and design system	Select and design corrective action measures	Select and design preventive measures
Implement detection system	Implement corrective action stragtegy	Implement preventive measures
Evaluate performance	Evaluate performance	Evaluate performance
Programs		
Monitor sources	Correct sources that are causing contamination	Prevent sources from causing contamination
Monitor supplies	Correct supplies (uses) that are contaminated	Prevent supplies from becoming contaminated
Monitor groundwater resources (e.g., ambient quality)	Correct groundwater resources that are contaminated	Prevent groundwater resources from becoming contaminated
Inventory sources		

SOURCE: Office of Technology Assessment.

gram to be implemented.[3] Examples of how these three elements influence the need for information about the hydrogeologic environment and water quality in a hydrogeologic investigation is described below.

Objective. At a given site, an objective to detect contamination will generally require less detailed water quality information than an investigation to correct contamination. For example, in a detection investigation it may be sufficient to define the boundaries of a contaminated area; in a correction investigation, more detailed information about variations in contaminant concentrations within the area may be necessary to evaluate correction alternatives.

Steps. Steps in meeting an objective also influence the level of detail to be obtained about water quality and the hydrogeologic environment. Investigations to evaluate the feasibility of options generally require less detailed information than investigations to select and design the action.

Program. Different kinds of programs may require different kinds of information. A detection program for water supplies may be limited to identification and quantification of contaminants in public water supplies, as required under the Safe Drinking Water Act. Monitoring under such a program is relatively straightforward because the measuring points are defined as the existing water supply wells, and the type of information required is water quality data. There is no need to evaluate the hydrogeologic environment to determine where to collect samples. However, samples taken without information about the hydrogeologic environment and associated flow system provide only a single snapshot of water quality—at the place and at the time the sample is collected; they cannot be used either to predict whether water quality is likely to change or to indicate the location of the source of contamination. Alternatively, a detection program to determine whether a source is in fact contaminating groundwater requires information on the hydrogeologic environment near the source—in addition to the collection and analysis of water quality samples—in order to identify areas that are most likely to show evidence of contamination.

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[3] Other factors, such as different motivations for conducting investigations (e.g., a State environmental program investigating threats to public health; an industry complying with regulatory requirements; and an industry investigating potential liabilities associated with known contamination), also influence the nature of the investigation in terms of funds, time, and expertise that are devoted to the task.

Design of Hydrogeologic Investigations of Groundwater Contamination

Information Requirements

Contamination investigations require information on the hydrogeologic environment, water quality, sources of contamination, and properties of contaminants, as shown in table 25.[4] The importance of this information in understanding the behavior of subsurface contaminants is also presented in table 25. The major points of the table are summarized below:

- The *primary purposes* for collecting hydrogeologic data are to determine the rate and direction of groundwater flow, evaluate the types of contaminants likely to be found, and determine whether the contaminants and the groundwater are likely to be moving at the same rate and direction.
- *Information on the hydrogeologic environment* (i.e., surface conditions—topography, vegetation, climate and surface water hydrology; geology; and subsurface hydrology—unsaturated zone, groundwater hydrology, contaminant transport parameters, and groundwater use) is obtained primarily to describe the flow of groundwater. Evaluating flow involves the collection of data on the quantity, timing, rate, direction, and pathways of water moving from the surface through the unsaturated zone and into and through the saturated zone.

  Information about the hydrogeologic environment is important in understanding whether contaminants will move at the same rate as groundwater or if physical, chemical, and/or biological processes are likely to occur that will cause them to move at different rates.[5] Analysis of the physical, chemical, and biological properties of the hydrogeologic environment, along with information on the properties of contaminants, is needed to evaluate the behavior of contaminants in the subsurface.

  The hydrogeologic environment is dynamic, and information on spatial and temporal variations is also important to assess contamination problems accurately. Some human activities can influence the flow of groundwater (e.g., pumping groundwater for use can alter the direction of flow, and modifications to the land surface can alter the amount of water infiltrating to the groundwater system).
- *Information on water quality* is collected primarily to determine the nature and/or verify the extent of contamination. Water quality information also contributes to knowledge of the nature and rate of chemical and biological reactions that influence contaminant behavior.
- *Information on sources* of contamination is useful in predicting the types of contaminants likely to be present, their locations, and their concentrations. When interpreted along with data on groundwater flow and associated contaminant behavior, source data can be used to predict the location, rate, and direction of contaminant movement. Knowledge of sources aids in determining the area to be in-

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[4] Hydrogeologic terms are defined in app. D.

[5] **Chemical and biological processes** can alter the rate of contaminant movement, change contaminant concentrations, and transform the contaminants that are present. These processes are a function of both the properties and concentrations of the contaminants present and the properties of the hydrogeologic environment (i.e., the unsaturated and saturated zones). Chemical processes include: adsorption-desorption, oxidation-reduction, acid-base, solution-precipitation, ion pairing or complexation reactions; and radioactive decay. Chemical processes are least significant in clean sand aquifers and some crystalline environments. Biological processes may be direct (e.g., enzyme activity) or indirect (e.g., production of metabolites; alteration of pH and Eh conditions; and provision of a surface for the accumulation and concentration of contaminants). Biological processes may result in the uptake, decay, or transformation of organic materials or the generation of additional contaminants. These processes can be particularly confusing in investigations of a source when information is available on the original contaminants but not on their altered states. For example, biological processes can transform trichloroethylene (TCE) to vinyl chloride, tetrachloroethylene to trichloroethylene, and heptachlor to heptachlor epoxide (McCarty, 1984). Biological processes are most significant in zones of higher oxygen availability and larger pore spaces, such as the unsaturated zone.

Physical processes include dispersion, whereby dissolved contaminants spread in ways that would not be predicted if the contaminants were moving only with the groundwater. Dispersion is a function of the hydrogeologic environment. It is independent of the properties of the contaminant. Dispersion results in an apparent faster movement of contaminants, relative to the average groundwater flow, at lower concentrations. Dispersion is especially important in fractured systems.

Table 25.—Importance of Information Used in Hydrogeologic Investigations[a]

Information obtained for hydrogeologic investigations[b]	Importance of information for understanding contaminant behavior in subsurface
I. Information on the hydrogeologic environment	
A. Topographic data	Provide partial information on flow (i.e., rate, directions, and pathways of unsaturated zone and groundwater flow and relationship of groundwater to surface water including: relative position of water levels in wells, locations of possible discharge and recharge areas, rates of infiltration and surface runoff, and general direction of groundwater flow).
B. Vegetative data	Provide partial information on flow (i.e., rate and pathways of water movement into and out of the subsurface). Also vegetation type and condition may reflect the quality of groundwater and be used to identify areas of contamination. Used to estimate depth to water table and identify possible discharge and recharge areas.
C. Climatic data (precipitation; evapotranspiration; site temperature)	Provide partial information on flow (i.e., the quantity, timing, and rate of movement of water and contaminants into the subsurface). Provide basic information to assess rate of reactions and biodegradation of contaminants.
D. Geologic data (surficial deposits; subsurface stratigraphy; lithology; structural geology)	Provide partial information on flow (i.e., location and volumes of potential groundwater supplies, pathways for water and contaminant movement into and out of underlying formations, and direction and rate of groundwater movement) and are used to identify possible recharge and discharge areas. Also, provide partial information on mechanical dispersion (mixing) and attenuation reactions of contaminants.
E. Surface hydrology data (overland flow; stream discharge; stage; recurrence interval; baseflow discharge)	Provide partial information on flow (i.e., quantity, rate, and timing of water movement into and out of subsurface). Used to identify and quantify possible discharge and recharge areas, and to identify potential conduits for contamination. Surface water may affect concentrations of contamination at discharge points.
F. Unsaturated zone data (water table; geometry; hydraulic properties: effective porosity, effective permeability, relative permeability, permeability, specific storage; flow parameters: pressure head, hydraulic gradient, fluid saturation; recharge/discharge: surface water characteristics, precipitation/ evapotranspiration)	Provide partial information on flow (i.e., on the flow regime which influences the rate, direction, and quantity of water and contaminants moving from the surface into the saturated zone). Usually relatively unimportant in the humid areas such as the Eastern United States.
G. Groundwater hydrology (Saturated Zone) data (aquifer characterization: confined aquifers, unconfined aquifers, leaky aquifers; hydraulic parameters of aquifers: storativity, transmissivity, primary permeability, secondary permeability, primary porosity, secondary porosity; confining unit geometry; hydraulic parameters of confining units: hydraulic conductivity, specific storage; flow parameters: water levels, hydraulic gradient, flow velocity; recharge/ discharge: surface water characteristics, precipitation contributions, confining layer leakage, fracture/matrix flux)	Provide partial information on flow (i.e., the rate, direction, and quantity, of groundwater and contaminant flow). Also, provide partial information on recharge and discharge characteristics.
H. Contaminant transport parameters (distribution coefficient; dispersivity coefficients; flow velocities; relative saturations; cation exchange capacity; subsurface mineralogy; ambient water chemistry; microbiology)	Provide partial information on properties of the hydrogeologic environment that influence the potential for physical, chemical, and biological reactions that result in contaminants moving at different rates than water through the groundwater flow system.

Table 25.—Importance of Information Used in Hydrogeologic Investigations[a]—continued

Information obtained for hydrogeologic investigations[b]	Importance of information for understanding contaminant behavior in subsurface
I. Groundwater use (current usage; projected usage)	Provides partial information on flow (i.e., the influence of groundwater pumping on the rate and direction of groundwater and contaminant flow). Also provides information on impacts of contamination.
II. Information on water quality (contaminants present; concentrations)	Provides data on concentrations and distribution of contaminants.
III. Information on sources of contamination (location; contaminants; release characteristics: location, volumes, contaminants, concentrations, timing) timing)	Provides data on types of contaminants that are likely to be present, requirements for collecting and analyzing samples, and suitability of different types of corrective action. Also provides data on flow (i.e., used to describe and predict the rate and direction of contaminant movement and the location of contaminants).
IV. Information on properties of contaminants	
A. Molecular-based properties	Provide information to identify which contaminants are present and at what concentrations.
B. Media-based properties	Provide information used as a basis for deducing contaminant behavior (e.g., persistence and mobility).

[a] Based on GeoTrans, Inc., 1983b.
[b] Hydrogeologic terms are defined in app. D.1.
SOURCE: Office of Technology Assessment.

vestigated, the sites for collecting water quality samples, and sampling and analysis procedures.

- *Information on properties of contaminants* is important in understanding the rate and direction of contaminant movement, the location of contaminants relative to the water table and less permeable units, the persistence of the contaminants in the subsurface, and the types of techniques that can be used to detect, correct, and prevent contamination.

  The properties of contaminants that are most important for their detection in the subsurface relate to solubility. Hydrogeologic investigations of contaminants that are only slightly soluble (immiscible) require more information on the hydrogeologic environment and water quality than may be needed to describe comtaminants that move with groundwater flow. Immiscible fluids that are also more dense than groundwater (e.g., many industrial solvents) may move in a different direction than groundwater flow. Immiscible fluids that are less dense than water (e.g., many petroleum products) tend to float on top of the water table and may require water quality sampling in the unsaturated zone.

Although all the hydrogeologic information shown in table 25 is useful for accomplishing investigation objectives for most site conditions, **the amount and types of information collected in practice is limited because of the time and costs of obtaining and analyzing data. The information collected varies, depending on site conditions and study objectives.** Examples of different information needs according to objectives were discussed in the preceding section on *Objectives*. The major site conditions that determine the information to be collected relate to the complexity of the hydrogeologic environment, the climate, the number of potential contamination sources, and knowledge of the behavior of the contaminants.[6]

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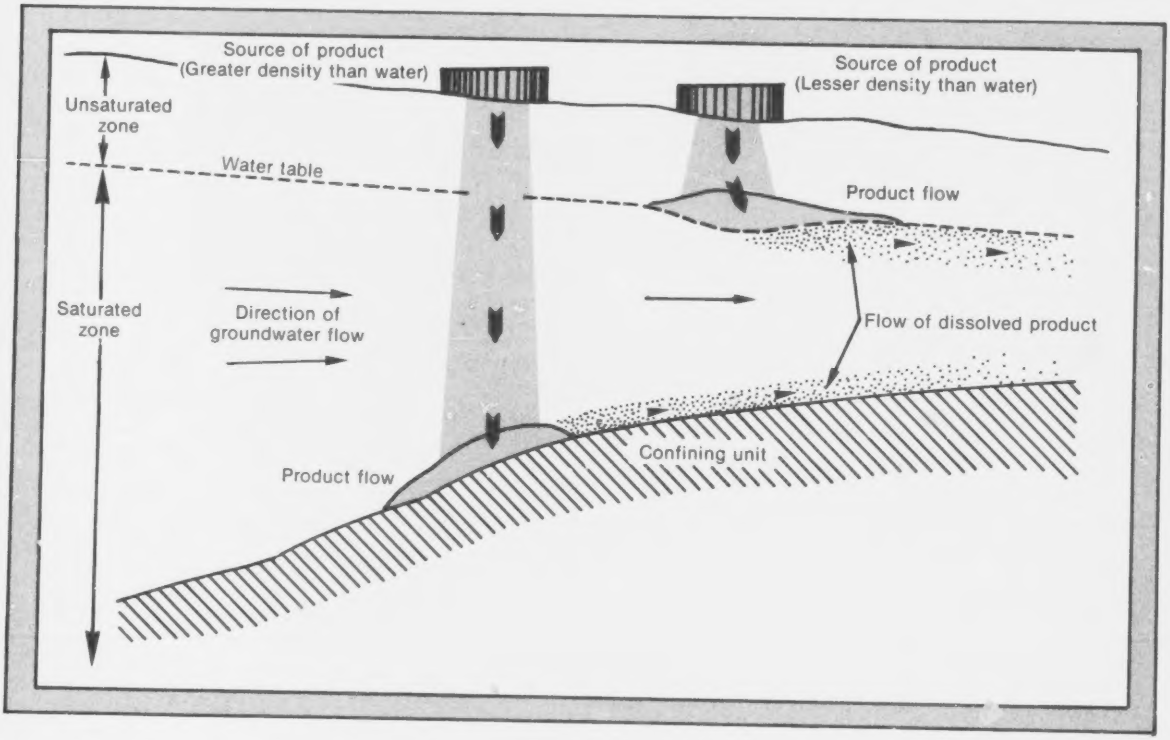
[6] Examples of variations in information collected under different site conditions are described below:

- In fractured (as opposed to unfractured) aquifers, information is needed on fracture patterns, joint patterns and spacings, and possibly dual porosity properties (i.e., primary and secondary permeability and porosity).
- In semi-arid (as opposed to humid) climates where the water table is deep, information on the properties of the unsaturated zone (e.g., moisture content and relationships between relative permeabilities and capillary pressure) is very important for defining groundwater flow and determining the potential for contamination.
- Where multiple sources (rather than a single source) of contamination are suspected, water quality sampling and analysis may be directed more to contaminants that are unique to a particular source, perhaps at very low concentrations, than to contaminants that are likely to be found at the highest concentrations.
- Where the behavior of contaminants can be readily described—for example, by having knowledge that the contaminant is quickly degraded or strongly retarded in groundwater—collection of data on water quality can be concentrated in areas near the source rather than over a wider area.


Source of product
(Greater density than water)
Source of product
(Lesser density than water)
Unsaturated zone
Water table
Product flow
Saturated zone
Direction of groundwater flow
Flow of dissolved product
Confining unit
Product flow

Credit: Geraghty & Miller, 1983

Immiscible contaminants that are more dense than water may not move in the same direction as groundwater flow. Immiscible contaminants that are less dense than water tend to float on top of the water table.

Techniques for Obtaining Information About the Hydrogeologic Environment

The presence and concentrations of most contaminants are determined from groundwater quality samples. Techniques for sample collection are discussed in this section on the hydrogeologic environment, and the analytical techniques for measuring the contaminants in a water quality sample are discussed in the next section on contaminants.

Techniques used to describe the hydrogeologic environment and to collect groundwater quality samples are organized into 12 major categories in table 26. The table outlines the general types of information obtained from the techniques and the limitations of the techniques under different conditions.

In general, some information on the behavior of subsurface contaminants can be obtained and interpreted with greater reliability than others. Groundwater flow can be readily described in most environments; however, information cannot be readily obtained on the physical, chemical, and biological processes that may cause contaminant attenuation. **This difference reflects both the state of scientific understanding and available technology.** For example, groundwater flow is better understood and mathematical modeling of flow is more highly developed than for contaminant behavior; thus data can be interpreted more reliably, and more accurate predictions can be made for groundwater flow than for contaminant behavior.[7] Summary points and findings from table 26 are highlighted below:

- **Techniques.** There are many techniques for obtaining information about groundwater flow and the movement of contaminants.

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[7] For a more detailed discussion of differences in models for groundwater flow and contaminant behavior, see OTA, 1982.

Table 26.—Techniques for Hydrogeologic Investigations: Information Obtained and Principal Constraints on Application[a]

		Major site contraints				
Techniques	Information	Subsurface geology	Subsurface hydrology	Water quality	Surface conditions	Other constraints
1. Unpublished and published information	To identify geologic, hydrologic, hydrogeologic, water quality, topographic, and climatic conditions.	Type of geologic formation: May not be sufficiently detailed for complex geologic settings.	Complexity of subsurface conditions: Usually data are unavailable for specific sites, but some regional hydrogeologic information may be useful, particularly in simple, uniform hydrogeologic settings.	Not a constraint.	Not a constraint.	Proprietary data may limit availability.
2. Mapping	To delineate surface geologic, soil, or topographic conditions.	Not a constraint.	Not a constraint.	Not a constraint.	Site access: Inaccessible terrain may be problematic during ground surveys.	Nonsite-specific information often adequate; represents separate cost. May require a relatively long time to complete (days to months).
3. Remote sensing (aerial photography and thermal, infrared, and radar satellite imagery)	To assess indirectly geologic, hydrologic, hydrogeologic, or water quality characteristics of the earth's surface. A reconnaissance tool to optimize surface field studies.	Depth: Techniques generally provide information on only face features but some techniques may provide some information on shallow groundwater flow and/or contaminant seepage within 10 feet of the land surface. Type of geologic formation: Some techniques can penetrate the surface and provide information on contaminants if under thin alluvium or sand.	Saturation conditions: Some techniques (e.g., radar) to detect presence of contamination are applicable only in unsaturated areas where there is a moisture difference between contaminated and uncontaminated areas. Flow system: Detectable contamination limited to discharge areas with techniques other than radar.	Nature of Chemical Compounds: Contaminant distribution can be detected by various techniques if chemicals stress vegetation, cause tonal changes in surface water, or thermal anomalies.	Climate: Some techniques are weather dependent; cloud cover interferes with all techniques except radar. Timing: Some techniques are accomplished best at different times of day (e.g., predawn or midday) and seasons.	Nonsite-specific information often adequate; represents separate cost.
4. Excavations and drilling	To access directly the subsurface environment for the purpose of geologic sampling, geophysical logging, water quality sampling, and fluid potential measurements.	Depth: Excavations generally only done at less than 20 feet. Applicability of different drilling techniques varies with depth; however, with use of proper equipment, holes can be drilled to virtually any depth. Type of geologic formation: Some drilling techniques can be used in only certain types of materials (soil versus rock, consolidated versus unconsolidated, prone to caving versus non-caving).	Not a constraint.	Nature of chemical compounds: Presence of certain contaminants may limit use of some drilling fluids to avoid sample contamination. Variations in contamination with depth may limit use of certain techniques to avoid cross-contamination.	Scale: Excavations can cover larger areas than drilling. Site access: It may be difficult to reach some sites (e.g., steep or marshy) with steep or marshy) with some types of equipment.	Property access: May require a relatively long time to complete (days to months). Relatively high cost to implement.

Table 26.—Techniques for Hydrogeologic Investigations: Information Obtained and Principal Constraints on Application[a]—continued

Techniques	Information	Major site contraints				
		Subsurface geology	Subsurface hydrology	Water quality	Surface conditions	Other constraints
5. Geologic sampling	To identify directly stratigraphy and geologic structure and to obtain geologic samples for laboratory testing of hydraulic and soil characteristics.	Depth: Type of sample that can be obtained depends on the depth and penetration capability of drill rig and/or sampling equipment. Depth is not a limiting factor for obtaining either undisturbed samples from some unconsolidated materials, or representative and non-representative samples from any type of materials.[b] Type of geologic formation: Some limitations depending on whether consolidated or unconsolidated. See Depth.	Not a constraint.	Not a constraint.	Not a constraint.	May require a relatively long time to complete (days to months).
6. Hydrometeorological measurements	To quantify temperature, precipitation, evapotranspiration, and infiltration at the earth's surface.	Not a constraint.	Not a constraint.	Not a constraint.	Not a constraint.	Field techniques to measure transpiration are difficult to apply, so estimates are usually made. Nonsite-specific information often adequate; represents separate cost.
7. Surface hydrology (hydraulic measurements; surface water sampling)	To identify flow and water quality characteristics of surface water.	Not a constraint.	Not a constraint.	Nature of chemical compounds: Difficult to obtain samples of many organic compounds that are only slightly water-soluble.	Not a constraint.	Nonsite-specific information often adequate; represents separate cost.
8. Subsurface Hydrology a. Potential measurements	To measure subsurface water level or pressure for evaluating direction of flow and to calculate flow rates within and between hydrologic units in both the unsaturated and saturated zones.	Depth: Depth is a limiting factor for some techniques (e.g., some tensiometers and drill stem tests). However, techniques are available to obtain measurements at any depth, provided specially designed wells are drilled. Type of geologic formation: Fine-grained, low permeability material limits the use of certain techniques (e.g., standpipes). However,	Saturation conditions: Choice of techniques depends on whether measurement is required for the saturated or unsaturated zone.	Not a constraint.	Not a constraint.	Not a constraint.

Table 26.—Techniques for Hydrogeologic Investigations: Information Obtained and Principal Constraints on Application[a]—continued

Techniques	Information	Major site contraints				Other constraints
		Subsurface geology	Subsurface hydrology	Water quality	Surface conditions	
a. Potential measurements (cont'd)		techniques are available to obtain measurements in any type of formation provided specially designed wells are drilled.				
b. Hydraulic testing	To determine the hydraulic properties of in-situ subsurface materials needed for calculations of flow rates in the unsaturated zones or directly measure groundwater flow velocities and to determine contaminant transport parameters.	Type of geologic formation: Some unsaturated zone techniques (e.g., infiltration tests) are impractical in coarse-grained soils due to the amount of water required. Choice of techniques (e.g., slug test, pressure injection test, and pump test) for saturated zone dependent on permeability of formation.	Complexity of subsurface conditions: Some techniques (e.g., slug tests and flow meters) measure conditions only at or near the point of measurement, and do not account for spatial heterogeneities. Saturation conditions: Some techniques are applicable in either saturated or unsaturated zones.	Not a constraint.	Not a constraint.	Relatively high equipment cost; intensive manpower requirements; and need for skilled personnel. May cause short-term changes in water levels. Tracers may have adverse environmental effects.
c. Laboratory testing (hydraulic, geologic)	To measure the hydraulic properties of samples of subsurface materials needed for groundwater flow calculations of variably saturated materials (e.g., porosity) and selected contaminant transport parameters (e.g., adsorption).	Depth: Testing dependent on obtaining appropriate type of sample (i.e., undisturbed, representative, or nonrepresentative). Type of geologic formation: Depends on whether consolidated or unconsolidated. See Depth. Provides good method of measuring permeability of fine-grained unconsolidated materials. Choice of geologic sampling technique (hydrometer v. sieve tests) depends on grain size.	Complexity of subsurface conditions: Superior to field measurements of vertical permeability of fine-grained unconsolidated materials. Major limitation is small sample size and the applicability of extrapolating point information to the three dimensional space being assessed.	Not a constraint.	Not a constraint.	Not a constraint.
d. Water quality sampling	To obtain a subsurface water sample representative of in-situ water quality for analyses of the presence and concentrations of chemicals and other substances in unsaturated and saturated zones.	Depth: Some pumps to evacuate wells and obtain samples have depth limitations. Type of geologic formation: In high permeability formations, evacuation of sampling wells to ensure sample is not affected by the well is problematic. However, techniques are available to minimize the amount of pumpage required	Complexity of subsurface conditions: Multiple completion wells to characterize vertical distribution of water quality are limited due to concerns about the effectiveness of sealing to prevent hydraulic connections and the ability to obtain representative samples from different sampling zones. Saturation conditions: Different techniques are used to obtain samples in the unsaturated zone	Nature of chemical compounds: Casing, well materials, and pumps must be selected both to resist deterioration from long-term exposure to natural chemicals or contaminants and to minimize interference with the measurement of specific constituents. Current knowledge of sampling interferences is limited for most well materials.	Not a constraint.	Not a constraint.

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Table 26.—Techniques for Hydrogeologic Investigations: Information Obtained and Principal Constraints on Application[a]—continued

		Major site contraints				
Techniques	Information	Subsurface geology	Subsurface hydrology	Water quality	Surface conditions	Other constraints
d. Water quality sampling (cont'd)		before sample collection, which may in turn limit selection of the most effective sampling equipment for particular constituents.		Design constraints of multiple completion wells (e.g., small diameter) may may limit use of most effective sampling equipment for some chemical parameters. Proper disposal of evacuation water prior to sampling is dependent on its quality. Techniques used to evacuate wells and obtain samples may result in incorrect measures of some compounds (especially dissolved gases and volatile organics). Also, the presence of some constituents (e.g., sediment) may damage some types of equipment. Some techniques allow excessive exposure to the atmosphere or other gases that might influence the measurement of specific parameters.		
9. Hydrogeologic system analysis (modeling; geostatistics)	To simulate or predict the behavior of subsurface hydrogeologic units, including groundwater flow and solute transport; or to estimate the values of hydrogeologic phenomena at unmeasured points.	Not a constraint.	Complexity of subsurface conditions: choice of modeling technique (i.e., analytic or numeric) depends on complexity of problem. Modeling complex systems limited by cost of obtaining data. Most geostatistical methods require that the sample population be normally distributed; thus if data represent complex subsurface conditions, geostatistical methods may be difficult or impossible to apply.	Not a constraint.	Not a constraint.	Relatively high cost to implement. May require a relatively long time to complete (weeks to months). Specialized skills required. Requires a clear definition of the hydrogeologic parameters used, including their variability in time and space.
10. Surface geophysics (electrical resistivity and electromagnetic conductivity; ground-penetrating radar; seismic refraction; shallow geothermic method)	To assess indirectly stratigraphy and extent of subsurface contamination to aid in placement of monitoring well sand to reduce number of wells.	Depth: Depth limitations are dependent on technique. Generally, techniques cannot be applied at depths greater than 500 feet. Type of geologic formation: Minimum detecta-	Complexity of subsurface conditions: Techniques applicable only in relatively simple stratigraphic conditions. Natural subsurface properties must be sufficiently uniform so as not to confuse or mask the effects of chemicals. Natural	Nature of chemical compounds: Chemicals of interest must be capable of both inducing a change in the subsurface parameter measured by the method and showing a different response than	Climate: Some techniques requiring electrode contact not applicable in frozen soils or in dry sandy areas (e.g., electrical conductivity). However, other techniques are applicable in these	Relatively high equipment cost; need for skilled personnel; may require a relatively long time to complete (weeks to months).

Table 26.—Techniques for Hydrogeologic Investigations: Information Obtained and Principal Constraints on Application[a]—continued

Techniques	Information	Major site contraints				Other constraints
		Subsurface geology	Subsurface hydrology	Water quality	Surface conditions	
10. Surface geophysics (cont'd)		ble concentration strongly influenced by properties of subsurface materials. Conditions that may prevent good results include: naturally conductive brackish water, steep water table, crystalline rock, and karst or other environs where groundwater flow is concentrated along interconnected fractures in massive bedrock.	conditions that may be responsible for false detection or nondetection include: discontinous, thick layers of clay; hydrogeologic heterogeneity; variations in natural groundwater chemistry due to changes in geologic materials; and variations in surface topography. Some methods are more effective than others for detecting small fracture zones containing high contaminant concentrations (e.g., electromagnetic conductivity is better than electrical resistivity). Homogeneous subsurface environments having layers of increasing densities present interpretative difficulties for some techniques (e.g., seismic refraction). All techniques generally require subsurface drilling or monitoring for verification of results. Saturation conditions: Some techniques can be used to obtain some types of information only in the unsaturated zone (e.g., electrical resistivity can track contaminant movement in only the unsaturated zone).	surrounding subsurface conditions. Many techniques (e.g., resistivity and conductivity methods) generally are ineffective for defining organic contaminant plumes. However, the presence of organic chemicals and petroleum products may be delineated in sand or gravel aquifers at depths generally less than 25 feet with ground penetrating radar. Relatively high concentrations required by techniques for detection of contaminants. Techniques only provide gross information on concentrations of some individual constituents. Some techniques can be effective in delineating extent of high concentrations of inorganic contamination in suitable geologic environments.	conditions (e.g., electromagnetic conductivity). Nature of surface: Conductors (e.g., metal fences, overhead power lines, paved areas, buildings, storage tanks, and buried pipelines or wires) may impair use of some techniques. Sensitivity of different techniques to these features is variable. Bare rock, wetlands, shallow lakes, and dry sandy areas prevent use of techniques requiring electrode contact.	
11. Subsurface (borehole) geophysics (acoustical; electrical-magnetic; nuclear; flow; thermal; geochemical)	To measure direct physical properties of subsurface materials to evaluate lithology, geologic structure, hydraulic properties, water quality, and flow.	Depth: Not a limiting factor for most techniques provided an uncased borehole can be drilled. Type of geologic formation: Most techniques can be used only in uncased boreholes, and thus cannot be used in geologic formations that cave in when drilled. Exceptions include nuclear logs which can be used in cased boreholes. Some tech-	Saturation conditions: Some techniques (e.g., electrical-magnetic logging techniques) are applicable only in saturated zone. Some techniques can be used to provide certain types of information in the unsaturated zone, and other types of information in the saturated zone (e.g., neutron logs).	Nature of chemical compounds: Some techniques applicable only if constituents in groundwater have properties that will induce response from instruments (e.g., spontaneous potential logs). Some techniques can be used to detect particular contaminants (e.g., Draeger tubes can detect over 140 in-situ soil gases).	Not a constraint.	Relatively high cost to implement.

Table 26.—Techniques for Hydrogeologic Investigations: Information Obtained and Principal Constraints on Application[a]—continued

Techniques	Information	Major site contraints				
		Subsurface geology	Subsurface hydrology	Water quality	Surface conditions	Other constraints
11. Subsurface (cont'd)		niques more suitable for obtaining information on particular types of geologic materials (e.g., natural gamma logs for obtaining clay unit properties).				
12. Hydrogeochemistry	To perform field testing of water samples to determine need for further laboratory chemical analysis and to analyze for unstable consituents.	Not a constraint.	Not a constraint.	Nature of chemical compounds: Field techniques available to obtain information on conductance, organic vapors, alkalinity, pH, Eh, DO, iron, and hydrocarbons. (See Subsurface Hydrology — Groundwater quality sampling, for additional constraints.)	Not a constraint.	Not a constraint.

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[a] Based on Geotrans, Inc., 1983b.

[b] *Undisturbed sample*—An in-place specimen in which features such as structure, density, and moisture content are essentially preserved. Suitable for laboratory testing of properties of geologic structure.
Representative sample—A disturbed sample in which some features do not survive but grain size and gradation are preserved. Suitable for grain size gradation analyses and obtaining knowledge of subsurface stratigraphy.
Nonrepresentative sample—A sample that may consist only of drill cuttings or other incomplete or contaminated portions of subsurface materials. Generally not suitable for testing or analysis. Somewhat suitable for subsurface stratigraphy.

SOURCES: Office of Technology Assessment; Geotrans, Inc., 1983b.

Photo credit: U.S. Geological Survey

Techniques are available for the direct sampling of groundwater quality.

- **Information Obtained.** Regardless of what techniques are used, which parameters are measured, and whether the measurements are taken directly or indirectly, all measurements must be interpreted in conjunction with other data to determine groundwater flow and the behavior of contaminants. Interpretation of data is uncertain because of factors relating to: the precision, accuracy, or detection limits of the equipment; lack of a unique measurement (e.g., geophysical response) for particular subsurface conditions; the degree to which averaging of conditions masks actual conditions; and the degree to which the sample or the measurement represents in-situ phenomena.

  Some techniques are useful in obtaining general information; others are used to obtain site-specific information. Some techniques (e.g., excavation and drilling) are not used to provide information per se, but their use is a necessary step before other techniques can be applied. Other techniques (e.g., mathematical modeling) are not used to measure properties of the hydrogeologic environment but can be used to simulate conditions and predict groundwater flow and movement of contaminants.

  Techniques are generally available to collect data on the unsaturated zone, groundwater hydrology, sources, and contaminants; this information is necessary to make reliable predictions of groundwater flow and estimate current and future water quality in most environments. However, historic data and data reflecting changes with time (e.g., groundwater use and the contaminant release characteristics of sources) are usually not available for a specific site, which diminishes the reliability of some investigations.

- **Constraints.** Factors that can limit the use of different techniques are related primarily to site conditions, costs, and the availability of skilled personnel. Additional constraints include problems with property access and the potential for adverse effects.

  Site conditions that can limit the use of hydrogeologic techniques include: subsurface geology (e.g., depth and type of geologic formation); subsurface hydrogeology (e.g., complexity of subsurface conditions, saturation conditions, and flow system); water quality (e.g., nature of the contaminants), and surface conditions (e.g., presence of buildings, pavement, power lines, vegetative cover, and other features; site accessibility; climatic factors; time of day; and size of the area).

  As shown in table 26, site constraints on obtaining information vary for different categories of hydrogeologic techniques as well as for specific techniques within each category (e.g., climate is a constraint only on certain remote sensing and surface geophysical techniques). Some techniques are limited to particular subsurface conditions (e.g., different techniques are used for the saturated zone than for the unsaturated zone). In addition, the site constraints that apply to a particular technique vary, depending on the purpose for which the technique is used (e.g., subsurface geology constraints on geologic sampling depend on the type of sample that is needed).

  There are a few types of information that cannot be obtained reliably using any technique including: chemical reactions in fluids containing multiple contaminants, properties characterizing in detail groundwater flow and chemical transport in fractured media, certain hydraulic properties of very low permeability media, in-situ determinations of hydraulic properties in the unsaturated zone when immiscible contaminants are present, and history of the contaminating source.[8]

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[8] See ch. 2 for discussion of the problems associated with determining the contribution of a source to groundwater contamination.

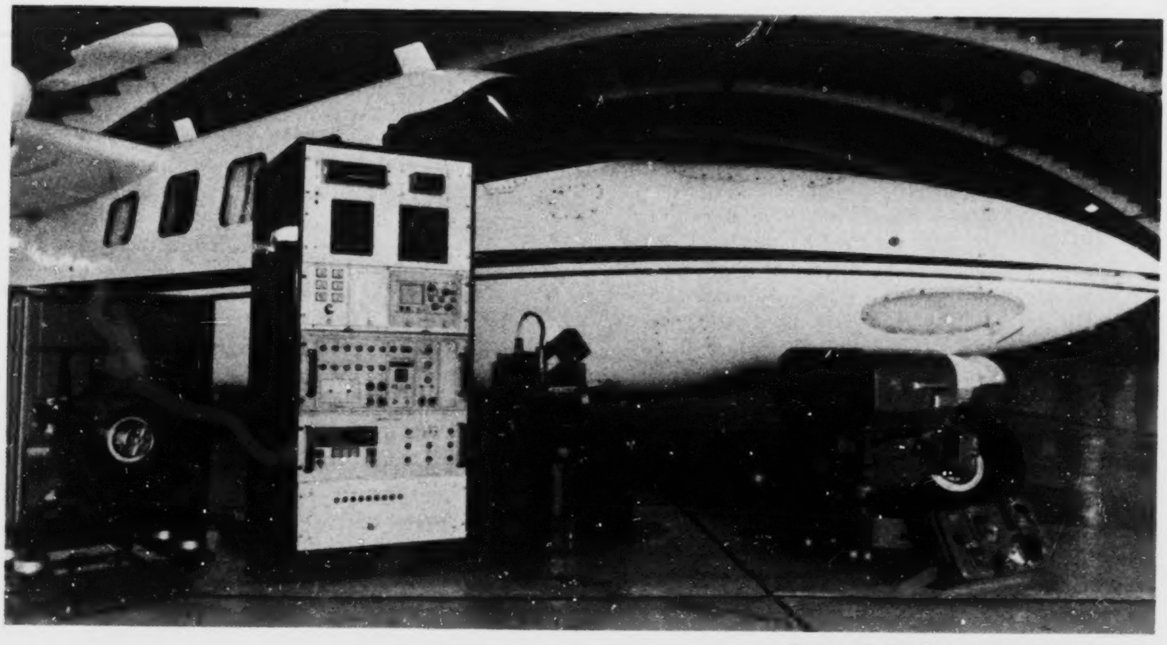

Photo credit: U.S. Environmental Protection Agency

Remote sensing equipment can be used to identify, document, and evaluate groundwater quality problems. The data acquisition system, which is mounted on the aircraft and operates 500-10,000 ft above ground level, includes (from left to right): an instrument logger for recording location, time, and altitude; a control console; a multispectral scanner; and an aerial mapping camera.

The *costs* of applying hydrogeologic techniques depend primarily on site conditions and the objectives to be achieved. Costs of hydrogeologic investigations to define contamination problems can range from $25,000 to $250,000, and litigation can double the figure (Miller, D., 1982). Many factors determine costs: the complexity of surface and subsurface conditions, areal extent of the study area, number and frequency of measurements, availability and quality of existing information, site access, experience and training of personnel, reliability and capability of equipment, availability of equipment, geology, weather, and the need for site-specific v. regional data. These same factors also determine the amount of time required, and they affect the choice of equipment and the number and locations of measurements to be taken.

Equipment costs limit the use of certain techniques (e.g., hydraulic testing, hydrogeologic systems analysis, surface geophysics, and subsurface geophysics). Either less costly or less sophisticated techniques are used. The costs of applying certain techniques (e.g. geologic sampling, potential measurements, water quality sampling, and subsurface geophysics) are reduced if a well or borehole can be used for more than one purpose. However, the information required to meet particular objectives will influence the decision on whether to use a single well or borehole for several techniques. Investigation costs can also be reduced by using indirect or field screening techniques to provide reconnaissance level information for selection of direct measurement locations.

Availability of reliable equipment capable of operating efficiently under the site conditions is an important factor in determining costs (e.g., choice of drilling methods and pumping equipment depends on site conditions). Capital expenditures for major equipment and materials vary, depending on the purpose and technical sophistication of the equipment. Certain types of equipment are more readily available in some areas of the country than others because of their other uses (e.g., subsurface geophysics equipment is used extensively for petroleum and mineral exploration).

The experience and training of personnel affect costs in terms of the level of skills needed to design an investigation and collect and interpret data. Highly specialized skills are required for some techniques, and skilled people are in short supply. The result is relatively high costs to obtain their services.

Property access may limit the use of drilling and associated techniques. Permission to drill wells is often not readily granted on private property because of the inconvenience and disruption created by the drill rig. Interest in drilling beyond property boundaries is often quite low because whoever finances the drilling must usually assume liability for damages.

The potential for short- or long-term *adverse effects* limits the use of some techniques. For example, short-term changes in water levels during hydraulic pump tests may limit their use in some environments (e.g., where there are water supply wells). Use of tracer tests is unacceptable to many regulatory authorities because tracers (some of which may be radioactive) may remain as a potential contaminant in the environment.

Techniques for Obtaining Information About Contaminants

Advances during the last decade in techniques for analyzing water quality samples—for identifying increasing numbers of specific substances, for detecting substances at progressively smaller concentrations, and for increasing the automation of instrumentation—have been major driving forces behind the detection of contaminants in groundwater. Continued improvement is expected; not only will previously undetected substances be found but more will be detected at increasingly small concentrations.

Not all contaminants, however, can be detected at low concentrations using routinely available techniques. Further, the fact that certain substances *can* be measured at increasingly small concentrations does not mean that they need to be. Rather, analysis should be guided by the levels at which substances may cause adverse impacts (Environ Corp., 1983). Major unresolved issues concern which substances and concentrations to measure, given limited resources, in order to evaluate the risks to public health and to provide the public with confidence that it is being protected.

At present, techniques for measuring substances in groundwater are not being used consistently, and they introduce a bias in terms of which of the substances present are detected. In addition, analytical accuracy becomes increasingly difficult to achieve as concentrations become very small and mixtures become more complex (Woodward-Clyde Consultants, 1983; Shifrin, 1984).

Properties of Substances.—Analyzing contaminants in a groundwater sample is based on the capability of instrumentation to discern certain properties of substances. These properties are important in contamination studies because they are characteristic of either individual substances or groups of substances and because they determine the nature, behavior, and response of substances under various conditions.

In the context of groundwater contamination, a distinction can be made between two types of properties, molecular-based and media-based (Woodward-Clyde Consultants, 1983).[9] Measurement of these two types of properties is based on different principles. In addition, the two relate to different objectives. For example, the *detection* of contaminants in a groundwater quality sample (e.g., determining the general presence of substances or identifying and/or quantifying the concentrations of specific substances) is based principally on the measurement of molecular-based properties. Molecular-based properties are derived solely from the basic construction of the substance: 1) elemental composition (i.e., elements and their frequency of occurrence in a molecule); 2) structure (i.e., spatial arrangement of elements); and 3) functional group (i.e., arrangement of elements into stable combinations). In contrast, media-based properties are the principal basis for characterizing the *behavior* of contaminants. Understanding behavior is necessary for designing hydrogeologic investigations including: evaluating the applicability of corrective actions, assessing the vulnerability of an aquifer to contamination, and assessing health and environmental impacts. Media-based properties are derived not only from the basic construction of a substance but also from its concentration in solution (in this case, in groundwater) and its interaction with the surrounding (e.g., hydrogeologic) environment. Although molecular-based and media-based properties are interrelated by molecular composition, this interrelationship is not well understood.

Information examined as part of this study, about the current status of the techniques for analyzing substances that are found in groundwater, is summarized below.

Measuring Molecular-Based Properties.—Many analysis techniques are available for measuring the molecular-based properties of substaces in groundwater, as shown in tables 27 and 28 (Woodward-Clyde Consultants, 1983). Many of these techniques are routinely available and have been standardized—i.e., they are "referenced" and published by the scientific community. Many standardized techniques have also been sanctioned by EPA—i.e., protocols have been established to ensure that the regulated community applies techniques consistently and to facilitate enforcement.[10]

With *general* (also known as non-specific, surrogate, or indicator) *methods,* it is possible to discern molecular-based properties that are common to, and hence can be used to determine the presence of, groups or classes of molecules. The major advantages of general methods are that they are relatively inexpensive in terms of both capital costs and costs per sample, and their use requires neither sophisticated equipment nor highly skilled technical personnel. The shortcomings include that many general methods can neither measure low concentration levels (i.e., several parts per billion or less)

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[9] For the purposes of this study, substances have been organized into nine groupings (see ch. 2, footnote 7 and table 6).

[10] Standardized methods have been subjected to statistical tests of precision (i.e., the reproducibility of results) and accuracy (i.e., the proximity of the measured results to the actual value) when used to detect substances in a *representative* group of samples. Detection using standardized methods therefore is not to depend on the specific nature of the sample.

Development of analytical methods for measuring substances in water has intensified since the passage of the Federal Water Pollution Control Act Amendments of 1972. The act's requirements triggered widespread analysis of surface water as well as municipal and industrial effluents for biochemical oxygen demand (BOD), chemical oxygen demand (COD), and other general parameters. Enforcement of regulations developed pursuant to the 1972 Amendments led to the need for a high degree of uniformity in the conduct of analytical programs to ensure consistency and equity within the regulated community. EPA first sanctioned the use of methods for measuring both general parameters and specific parameters in EPA, 1974 (revised 1979).

Table 27.—Analytical Methods for Measuring the Molecular-Based Properties of Groundwater Contaminants[a]

Methods	Contaminants measured	Routinely[b] Available
Organics		
General methods		
TOC (total organic carbon)	Carbon-containing	Yes
UV (ultra-violet spectroscopy)	Aromatic hydrocarbons	No
FLUOR (fluorescence)	Polynuclear hydrocarbons	No
RI (refractive index)	Soluble organics	No
4AAP (4-aminoantipyrene)	Phenols	Yes
TKN (total Kjeldahl nitrogen)	Nitrogen-containing	Yes
MBAS (methylene blue active substance)	Sulfonate detergents	Yes
TOX (total organic halogen)	Halogenated organics	Yes
O&G (oil and grease)	Oil and grease in solution	Yes
TP (total phosphorus)	Phosphorus-containing (both for organics and inorganics)	Yes
Contaminant-specific methods[c]		
Isolation systems		
Separaton systems		
GC (gas chromatography, both gas-liquid and gas-solid)	Organics	Yes[d]
HPLC (high performance liquid chromatography)	Polynuclear aromatics	Yes
Detection systems		
CD (conventional detectors)	Organics	Yes
MS (mass spectrometry)	Organics	Yes
Inorganics		
General methods		
Eh (Oxidation potential)	Oxidizing metals	Yes
Specific conductance	Ionized species	Yes
pH/acidity	Mineral acids	Yes
Contaminant-specific methods		
AA (atomic absorption spectrometry)	Metals/cations	Yes
ICAP (induction-coupled argon plasma)	Metals	Yes
Wet chemistry		Yes
Colorimetry	Non-metals/anions	
Gravimetry	Metals	
Titrimetry	Acids	
Radionuclides		
General methods		Yes
Gross emission		
Contaminant-specific methods		Yes[e]
Concentration/identification		
Microorganisms		
General methods		Yes
Standard plate count	Aerobic and facultative anaeorbic, heterotrophic bacteria	
Multitube fermentation	Coliform bacteria	
Membrane filtration	Coliform bacteria, pathogens, parasites	
Contaminant-specific methods		Yes[e]
Culturing	Pathogens	
Morphology	Parasites, fungi	
Concentration/identification		

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[a] Based on Woodward-Clyde Consultants, Inc., 1983.

[b] Methods examined for this study are those that are "referenced," or published, and commercially available. Less common techniques include innovative (R&D) methods such as "triple quadrupole mass spectrometry" and "tandem mass spectrometry" (as reported in *Environ. Sci. Tech.* Vol. 15, No. 6, 1982) and special methods such as ion chromatography, size exclusion chromatography, and infrared spectroscopy.

[c] There are typically three stages in this analysis; isolation of the contaminant (e.g., via headspace analysis, purge-and-trap, or liquid-liquid extraction), separation (e.g., via gas chromatography or high performance liquid chromatography), and detection (e.g., via conventional detectors such as flame ionizaton, electron capture, or via mass spectrometry).

[d] GS/MS is standardized for chemical subgroups, specific members of which are on the Priority Pollutant List, and for pesticides regulated under the CWA.

[e] These contaminant-specific methods are time-consuming, costly, and tend to be reserved for research and specialty applications.

SOURCE: Office of Technology Assessment.

Table 28.—Costs and Detection Limits of Methods for Measuring the Molecular-Based Properties of Contaminants[a]

	Costs[b] ($)		Detection limits[c]	
Method	Per sample	Capital	(ppm)	(ppb)
Methods for measuring organics				
General methods				
TOC	15–30	9,000–15,000	1	1,000
UV	30–60	12,000–30,000	(0.1)[d]	(100)
FLUOR	20–40	5,000–16,000	(1)	(1,000)
RI	10–30	5,000–12,000	—	—
4AAP	30–60	4,000–6,000	0.002	2
TKN	20–30	4,000–6,000	0.002	2
MBAS	20–40	1,000–2,000	0.025	25
TOX	60–100	8,000–10,000	0.01	10
O&G	20–30	500–1,500	0.2	200
TP	30–70	1,000–2,500	0.01	10
Contaminant-specific methods				
GC/CD	30–500	8,000–30,000	< 0.001–0.1	< 1–100
GC/MS	100–1,500	55,000–220,000	< 0.001–0.01	< 1–10
HPLC	40–500	8,000–40,000	0.000001	0.001
Methods for measuring inorganics				
General methods				
Eh[e]	10–15	1,000–1,500	N/A	
Specific conductance	3–5	1,000–1,500	N/A	
pH	3–5	1,000–1,500	± 0.1 pH unit	
Acidity	10–15	500–1,000	± 0.1 mg $CaCO_3$/l	
Contaminant-specific methods				
AA	150	12,000–20,000	< 0.001–0.2	< 1–200
ICAP	125–200	125,000–175,000	< 0.001–0.2	< 1–200
Wet chemistry	10–35	2,000–5,000	0.1–1	100–1,000
Methods for measuring micro-organisms				
General methods	75/group	2,500–4,000	N/A	
Contaminant-specific	1,000/strain	2,500–4,000	N/A	
Methods for measuring radionuclides				
General methods	40–75	5,000–7,000	1-2 pCi/l	
Contaminant-specific	1,000–1,500	30,000–60,000	1-100 pCi/l[f] 0.05-1 pCi/l[g]	

[a] Based on Woodward-Clyde Consultants, Inc., 1983; additional information in Brass, 1982, and Vicory, et al., 1982.

[b] Approximate cost ranges are presented only for general comparison. In practice, costs will depend on many factors including the level of automation of the equipment, the need for auxiliary apparatus, the sophistication of the data system, and the work load of the laboratory (e.g. number of analyses to be performed, lead-time available, and required turn-around time).

[c] Detection limits are not absolute and will depend on such factors as the contaminant to be measured, interference among contaminants contained within the sample, sample size, methodology, and skill and experience of the analyst. In practice, levels of accuracy and precision would need to be specified in order to interpret the data. Detection limits are generally presented with the following units:

1 mg/l (milligrams per liter) = 1 ppm (parts per million)
1 ug/l (nanograms per liter) = 1 ppb (parts per billion)
1 ppb = 1,000 ppT (parts per trillion)
1 ppm = 1,000 ppb

[d] Detection limits in parentheses are presented only as examples for non-standardized methods.

[e] Some contaminants, such as oxidizing metals, are unstable and need to be measured in the field.

[f] For alpha, beta emitters.

[g] For gamma emitters.

SOURCE: Office of Technology Assessment.

nor identify individual substances of a group or class. Individual substances would be of concern if they were expected to vary in terms of their potential impacts. In addition, data from general methods can be difficult to interpret, especially when interferences arise from the presence of several different types of substances in the sample. These interferences are known to give misleading results ("false positives") (Davis, 1984).

With *contaminant-specific methods,* it is possible both to identify individual substances and to quantify their concentrations at extremely low levels. The disadvantages of contaminant-specific methods are that they are more costly than general methods, and they require the use of relatively sophisticated equipment. These methods, as well as general methods, are also subject to quality control problems with analysis procedures, and data can be difficult to interpret (e.g., there will always be some degree of uncertainty about how well data represent in-situ conditions).

Three important points about measuring molecular-based properties are discussed below related to: 1) which substances can be measured, 2) the extensive use of gas chromatography/mass spectrometry (GC/MS), and 3) the "standardized" concept as it relates to groundwater contamination (see Woodward-Clyde Consultants, 1983).

***Substances Measured.*—Not all known or potential substances can be detected at trace levels using routinely available standardized methods.** Some of these substances have been, or may be, associated with toxic effects in either clinical or laboratory studies.

Organic chemicals:

- There are **no routinely available general methods for measuring trace levels of some organic chemicals known to occur in groundwater,** including aromatic and polynuclear hydrocarbons. There are no general methods for measuring trace levels of some substances that have the potential to be found in groundwater—e.g, glycols and oxygenated hydrocarbons such as aldehydes, ethers, esters, ketones, and alcohols.
- **Standardized contaminant-specific methods** —namely gas chromatography/mass spectrometry, GC/MS—**tend to be available for only selected organics** (i.e., 129 "Priority Pollutants" and pesticides regulated under CWA).[11]
- There are **no cost-effective methods for measuring many "exotic" chemicals,** including some pharmaceuticals, specialty chemicals, and chemical products of research and development efforts (e.g., for new pesticides). These chemicals are generally not manufactured in large quantities or widely dispersed but still may be of concern in selected locations. Their detection will depend on factors related to available analytic equipment, available time, laboratory skills, cost, and knowledge about their manufacture, use, and disposal (Davis, 1984).

Inorganic chemicals, micro-organisms, and radionuclides:

- Inorganic chemicals, micro-organisms, and radionuclides can be measured with standardized general and contaminant-specific methods. There are no standardized methods, however, for measuring viruses.

Use of GC/MS.—The contaminant-specific methods sanctioned by EPA favor the use of GC/MS (e.g., GC/MS is required during the permit application process under the NPDES program [40 CFR 136]). GC/MS has gained in popularity in recent years, both to detect known or suspected substances in groundwater and to scan a sample of unknown composition. GC/MS has regulatory advantages (e.g., protocols have been established to ensure uniformity of application and to facilitate enforcement), and it produces data about specific chemicals.

Reliance by EPA on standardized GC/MS methods is limited in three major ways:

1. **Some substances cannot be detected with these methods,** including substances of high

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[11] A 1976 consent decree settling lawsuits brought by a number of environmental organizations against EPA for failure to implement certain requirements of the 1972 Act and the 1977 Amendments to the Act (the Clean Water Act) focused attention on the control of toxic pollutants. (See *Natural Resources Defense Council, et al.* v. *Train,* June 8, 1976, 8 ERC 2120. Several provisions of the consent decree were incorporated into the 1977 Amendments.) EPA was required to establish technology-based effluent standards for 65 classes of toxic pollutants (129 "Priority Pollutants") in 21 major industrial categories. Methodology for the analysis of the Priority Pollutants was proposed in December 1979 (44 FR 69464). Specific chromatographic methods for pesticides are described in EPA, 1983.

Photo credit: U.S. Environmental Protection Agency

Gas chromatography/mass spectrometry equipment is used for the qualitative identification and quantitative measurement of individual organic chemicals.

molecular weight, substances that are unstable at high temperatures, and substances that are highly soluble in water. In many of these cases, relatively simple, modified versions of some standardized GC/MS procedures are adequate (e.g., for malathion); in other cases, entirely different methods, such as High Performance Liquid Chromatography (HPLC), may be required (Davis, 1984). Specialized modifications of standardized GC/MS methods may also be possible for additional substances such as dioxin (2,3,7,8-TCDD); dioxin is difficult to detect because it is relatively insoluble in water and often present at concentrations of only parts per trillion. In general, none of these other techniques have been standardized and used routinely.

2. Standardized GC/MS methods could be applied directly (i.e., without modification) to substances in addition to the Priority Pollutants (e.g., xylenes and aniline). Although EPA has made significant research and development commitments to improve the basic instrumentation of GC/MS and associated data processing systems, **less attention has been given to widening the routine use of standardized GC/MS methods for additional substances** (e.g., by expanding the list of Priority Pollutant organics).
3. While contaminant-specific techniques, such as standardized GC/MS methods, are cost-effective for identifying substances in a sample of *unknown* composition *if* the substances are amenable to analysis by the methods, the methods may be otherwise inefficient (i.e., very costly) for unknown samples. **Little research attention has been given to developing techniques for substances not amenable to analysis by GC/MS or to developing reliable and inexpensive screening techniques** (e.g., alternative types of analytical and physical/chemical testing methods) for narrowing the universe of potential substances that might be present in a sample and therefore for efficiently determining which contaminant-specific techniques are most applicable (Davis, 1984; Woodward-Clyde Consultants, 1983).[12]

Standardized Methods.—Central to the standardization of methods is the concept of a representative sample (refer to footnote 10). This is a difficult concept to apply to groundwater samples because groundwater contamination is site-specific, and the "representative samples" used to standardize a method may not represent the universe of groundwater samples to which the method might be applied. Thus the use of a standardized, routinely available method does not guarantee that substances in groundwater can be detected with the precision and accuracy indicated by following the standard procedures.

Measuring Media-Based Properties.—Once substances in groundwater have been identified by measuring their molecular-based properties, it is often essential to understand their behavior. Behavioral characteristics—e.g., persistence and mobility—determine, for example, the extent of the contamination problem and likely impacts. However, with present techniques, behavioral characteristics of a substance cannot be measured directly. Rather, the characteristics are deduced from the media-based properties of the substance. These properties are determined by the nature of the substance in relation to its surrounding environment. Each behavioral characteristic typically requires information on a *combination* of media-based properties.[13]

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[12] "The issues of the presence of groundwater contamination and its extent are not resolved economically or universally by the extensive use of GC/MS . . . The failings of the GC/MS protocol are not, in fact, limitations of the protocol itself. They are, rather, instances where the protocol can be either erroneously assumed to be a complete assessment of groundwater contamination, or erroneously determined to be (either) the optimum means of determining a contaminant's identity and concentration in groundwater, or the most cost effective means of gathering data to achieve one of the identified objectives" (Woodward-Clyde Consultants, Inc., 1983, ch. 5, pp. 6, 33).

Standardized analytical methods are generally available for measuring individual media-based properties (see table 29). However, because media-based properties are site-specific and because numerous media-based properties are often of interest, determining the behavior of substances is a technically complex and time-consuming process that theoretically must be performed at each site. In practice, information about media-based properties is obtained primarily from physical and chemical measurements (taken both during the hydrogeologic investigation and in the laboratory) and from published data.[14] Behavior of a substance is then deduced using this information together with professional judgment and experience (e.g., to perform correlation analyses).

***Approaches for the Measurement of Substances in Groundwater.*—Techniques for measuring substances in groundwater are not now being selected and used consistently to ensure that all potential contaminants at a given site are being addressed, that substances are being detected efficiently given time and financial constraints, and that information obtained can be meaningfully interpreted,**

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[13] For example, the mobility of a substance cannot be measured directly, but mobility can be deduced from a combination of media-based properties, including adsorption, volatility (e.g., Henry's Law Constant), solubility, and chemical/biological reactivity; persistence can be deduced from such media-based properties as adsorption, bioaccumulation, partition coefficient, chemical/biological reactivity, and degradability.

[14] All sources of technical information have limitations in assessing the behavior of substances. Physical/chemical measurements are time-consuming and costly; high-quality data required for correlations are often not available; and published data are often incomplete, inconsistent, or imprecise. For example, published data are found in such references as Weast, 1978-1979; Perry, et al., 1973; EPA, 1981; Windholz, et al., 1983; and Sax, 1979. Data tend to be limited to such properties as density, viscosity, ignitability, corrosivity, miscibility, solubility, and vapor pressure. Information is not available for all substances and is often not sufficiently accurate for analysis of trace levels. Moreover, while some of these properties, such as ignitability and corrosiveness, are used for classifying wastes as hazardous (under RCRA), they contribute little information about the behavior of such substances in groundwater. Other properties that are of interest to groundwater contamination studies, such as adsorption, bioaccumulation, and the partition coefficient (i.e., the tendency of a substance to partition between soil and water) are not generally available and must be measured using groundwater samples.

Table 29.—Techniques Commonly Used To Measure Media-Based Properties of Contaminants

Media-based property	Techniques employed
Density	Measure forces transmitted by a mass of the substance being analyzed as in viscous-drag, gas-density meter.
Viscosity	Measure fluid friction by either mechanical drag between driven and free members immersed in the sample or resistance to flow.
Adsorption	Use batch test or leaching columns.
Solubility	Dissolve measured amount of contaminant in a given volume of water at room temperature.
Volatility	Estimate quantity of contaminant vaporized from water by use of an Organic Vapor Analyzer (OVA).
Immiscibility	Shake contaminants in water and observe if there is complete mixing.
Bioaccumulation	Determine concentration of contaminant in sample (e.g., via fish) and compare with background level.
Reactivity	Observe violent reaction of contaminant and/or generation of toxic gases, vapors or fumes when mixed with water.
Degradability	Measure CO_2 evolution, or determine rate of disappearance of parent compound over time.
Stability	Observe disappearance of parent compounds or generation of daughter products.
Oxygen uptake	Determine biochemical oxygen demand (BOD) or chemical oxygen demand (COD).
Partition coefficient	Measure concentration of contaminant in soil relative to concentration of contaminant in water.

SOURCE: Woodward-Clyde Consultants, Inc., 1983.

given the objective (detection, correction, or prevention) of the measurement program. A coherent approach would consider measuring molecular-based properties with both general methods (e.g., as screening tools to narrow the choice of possible substances present) and contaminant-specific methods (e.g., to identify individual substances and determine their concentrations).[15]

EPA has made efforts in the direction of a master scheme for measuring substances (e.g., EPA Method 8600 is being developed as a comprehensive analytical scheme to determine the presence of chemicals listed in Appendix VIII of RCRA, Part 261). Agency efforts are not yet coordinated in a way that responds fully to the spectrum of substances found in groundwater and possibly at extremely low concentrations.

For example, the groundwater indicator parameters to be measured at both interim status facilities (40 CFR 265) and permitted facilities under the detection monitoring system (40 CFR 264) are delineated as pH, Specific Conductance, Total Organic Carbon (TOC), and Total Organic Halogens (TOX). Some substances known to cause adverse health impacts are not detectable using the indicator parameters. TOC and TOX measurements have the disadvantages of general methods discussed above (e.g., subject to interference effects). In addition, there are categories of contaminants that are neither halogenated, acidic, nor conducting and that may be toxic at less than 1 part per million (ppm, the detection limit of TOC) including pesticides and pesticide byproducts (e.g., dioxin and 2,4,5-T, both of which are known to occur in groundwater; see ch. 2) (Woodward-Clyde Consultants, 1983). "To a great extent, because of an overreliance on indicator parameters, we don't know much more now about which sites are 'clean' or 'potentially dirty' than we did before EPA started using the indicator monitoring approach 3 years ago" (Davis, 1984).

Monitoring Networks

Hydrogeologic investigations involve collecting information about the hydrogeologic environment and water quality at selected locations and then making assumptions about what is likely to be occurring between sampling points. In general, the more the sampling points, the less uncertainty is associated with interpretation of what is taking place in the subsurface. But practical considerations limit the number of measurements taken. The number of measuring points (for direct techniques), the density of measurements (for indirect techniques), and the verification that is required to obtain a satisfactory level of confidence in the results depend on site conditions and the objective of the investigation.

To account for horizontal and vertical variations in the hydrogeologic environment and in water quality, both the *location of sampling points* and *sampling frequency* will vary depending on site conditions and objectives. For example, measuring points could be located at random or in an evenly spaced pattern, or in relation either to the pathways of substances (i.e., measuring points are located where substances are either expected and/or not expected to be found) or to concentrations (i.e., measuring points are located where concentrations are highest and/or lowest). Sampling could be conducted once, annually, seasonally, or more frequently, depending, for example, on whether groundwater flow patterns change periodically.

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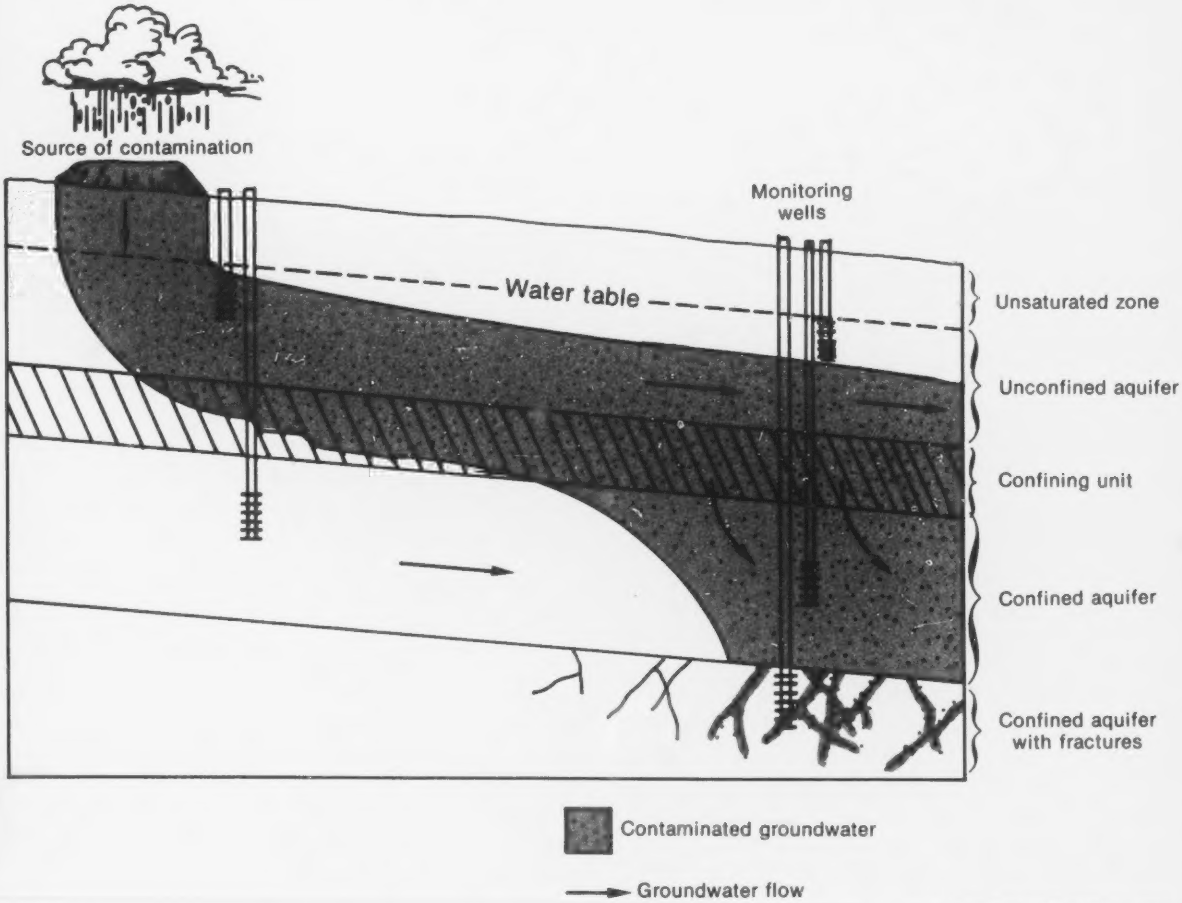
[15] Additional information about contaminant measurement can be found in EPA, 1979, 1981, 1982, 1983; Chapman, et al., 1982; Neal, 1983; and USGS, 1979.


Source of contamination
Monitoring wells
Water table
Unsaturated zone
Unconfined aquifer
Confining unit
Confined aquifer
Confined aquifer with fractures
Contaminated groundwater
Groundwater flow

Credit: Geraghty & Miller, 1983

In order to detect contamination, sampling wells need to be located at varying depths and distances from the source.

APPROACHES FOR MINIMIZING DIFFICULTIES WITH GROUNDWATER CONTAMINATION INVESTIGATIONS

Ensuring the Reliability of Hydrogeologic Investigations

As described in the previous sections, investigations of groundwater contamination are very complex and uncertain because the hydrogeologic environment is not easily observed, and hydrogeology varies both spatially and temporally. Hydrogeologists cannot describe and predict with absolute confidence the rate, direction, and pathways of contaminant movement in groundwater. Estimates can be made and ranges of values given but there will always be some degree of uncertainty about which contaminants are present, where they are moving, how fast they are moving, and their concentrations as they move.

Despite these uncertainties, investigations are under way, and they are used as a basis for making decisions about the need for and usefulness of alternative corrective and preventive actions. Given the nature of such decisions—e.g., regarding public health and the dollars involved—decisionmakers and the public need some assurance that certain elements of uncertainty are minimized and that hydrogeologic investigations provide reliable results.

Factors that tend to increase uncertainty in investigations of groundwater contamination include: complex hydrogeologic environments; lack of historic information about sources of contamination; substances that do not move with groundwater (because they are immiscible, or due to physical, chemical, and biological processes that alter their nature or retard their movement); changing patterns of groundwater use; and inexperienced or untrained individuals designing investigations and collecting and analyzing hydrogeologic information.

All of these factors reflect conditions at the site and are beyond the direct control of decisionmakers, except the choice of personnel. Most of the site-related factors that contribute to uncertainty can be overcome by an experienced hydrogeologist, provided sufficient time and funds are available. That is, steps can be taken such that the uncertainties do not undermine ability to make reliable predictions about the response of contamination to various corrective or preventive measures. For example, by collecting more information over a longer period on the presence of substances and the rate and direction of groundwater flow, investigators can reduce many uncertainties about complex hydrogeologic environments, sources of contamination, and changing patterns of water use. The one major exception, where reliable predictions are unlikely, is in fractured environments (e.g., karst regions of the southeastern United States).

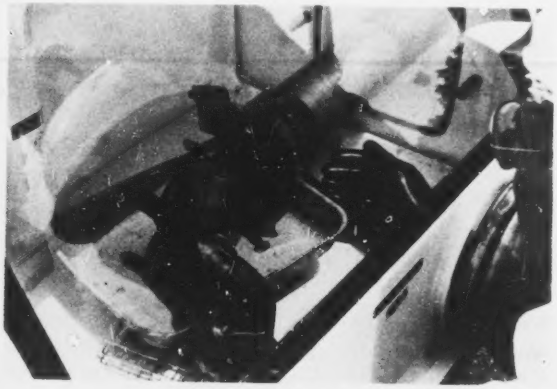


Photo credit: U.S. Environmental Protection Agency

Special precautions must be taken to ensure that samples are not contaminated by the sampling equipment. This photo shows aquifer material being extruded from a core sampling tube while a sterile shaving device removes material that has been in contact with the inside of the sampler.

Uncertainties about immiscible substances that do not move with groundwater can be reduced with the collection of more information, especially about the hydrogeologic factors that control the movement of such substances. The uncertainty associated with the behavior of substances that do not move with groundwater flow due to physical, chemical, and biological processes cannot be reduced significantly, given technical limitations in understanding these processes. However, precautionary steps can be taken to minimize the impact of this and any other remaining uncertainties, including: using sensitivity analyses to test the significance of varying assumptions about groundwater flow and the behavior of substances; using conservative or worst-case assumptions about groundwater flow as the basis for designing corrective or preventive measures; and continuing the monitoring of groundwater flow and water quality as part of the implementation of any program to correct or prevent contamination so that any errors in predictions about the response of contaminants can be recognized early and compensating actions can be undertaken.

These precautionary steps may lead to overdesign and higher costs for corrective or preventive measures. However, overdesign may be the only way to limit risks associated with the lack of precise knowledge about the concentration and location of substances and the rate and direction of their movement.

An additional step that can be taken to improve reliability, and perhaps to reduce future costs and time required, is to keep records on the use of groundwater and the location of potential sources and their associated substances. With these records the hydrogeologist will have a better idea about which substances are of concern at a site and where to look for them.

Approaches for Minimizing Difficulties in Measuring Substances

Analysis of water quality samples is a technically complex process, and the difficulties associated with accurate measurement and interpretation of data are discussed in the literature (e.g., Keith, et al., 1982b, 1983; Miller, S., 1982). Uncertainties can be introduced at many steps—including when the sample is collected, handled, transferred, stored, prepared for analysis, as well as analyzed (Shifrin, 1984). Thus, detection limits (as presented in table 28) are not absolute; they depend on many factors, including the skill and experience of the analyst, the combinations and concentrations of the substances present, and the equipment used. For example, acceptable ranges for precision and accuracy, used for EPA-sanctioned methods by contract laboratories, range from 15 to 50 percent and 15 to 200 percent, respectively, depending on the organic classes measured (Keith, et al., 1983).[16]

In all cases, uncertainties in the analytical results need to be defined if the data are to be correctly interpreted. This need is especially important for the **types of groundwater samples for which a high degree of accuracy is *not* now attainable—samples in which there are complex mixtures of substances, samples in which substances are present at trace concentrations, and samples being analyzed with relatively new analytical methods.**

Some uncertainties can at least be defined, if not reduced, through quality assurance/quality control programs. QA/QC programs, which are part of EPA's contract analysis program, need to consider sample handling and storage procedures, sample preparation, care of equipment, methods for assessing data for completeness, and record-keeping and documentation (ACS, 1980, 1982). Analysis of several samples is also important for obtaining statistically significant results. Other factors important for obtaining meaningful analytical results in groundwater contamination studies concern: the laboratory certification process,[17] laboratory selection, availability of background information (e.g. about sources and users), availability of information about the nature and history of the sample, independent confirmation of the quality of laboratory data, and guidance on the selection of appropriate measurement methods (Woodward-Clyde Consultants, 1983; Keith, et al., 1983).

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[16] With respect to precision, if acceptable precision is, say, 50 percent, then only those samples with concentration differences *greater* than 50 percent actually represent samples with differing concentrations. With respect to accuracy, an acceptable accuracy range of, for example, 75 to 115 percent implies that the observed concentration of a substance would have to be either: 1) lower than the true value by one-fourth, or 2) greater than the true value by 15 percent for the data to indicate that the substance was *not* present at the actual concentration.

[17] While the laboratory certification process is meant to promote the reliable generation and documentation of data, certification has certain limitations which should be examined on a laboratory-specific basis. For example, specific requirements for certification may vary by State or by region; certification status can change over time; certification usually is issued on a substance-by-substance basis and only at specified concentration levels (e.g., laboratory certification for compliance purposes under SDWA is issued only for substances covered by NIPDWR and for those concentration levels expected to be found in drinking water); and certification may apply either to individual personnel or to the entire laboratory.

Photo credit: U.S. Environmental Protection Agency

Standard reference materials are provided by EPA's Environmental Monitoring Laboratory to laboratories for instrument calibration and internal checks in order to evaluate performance.

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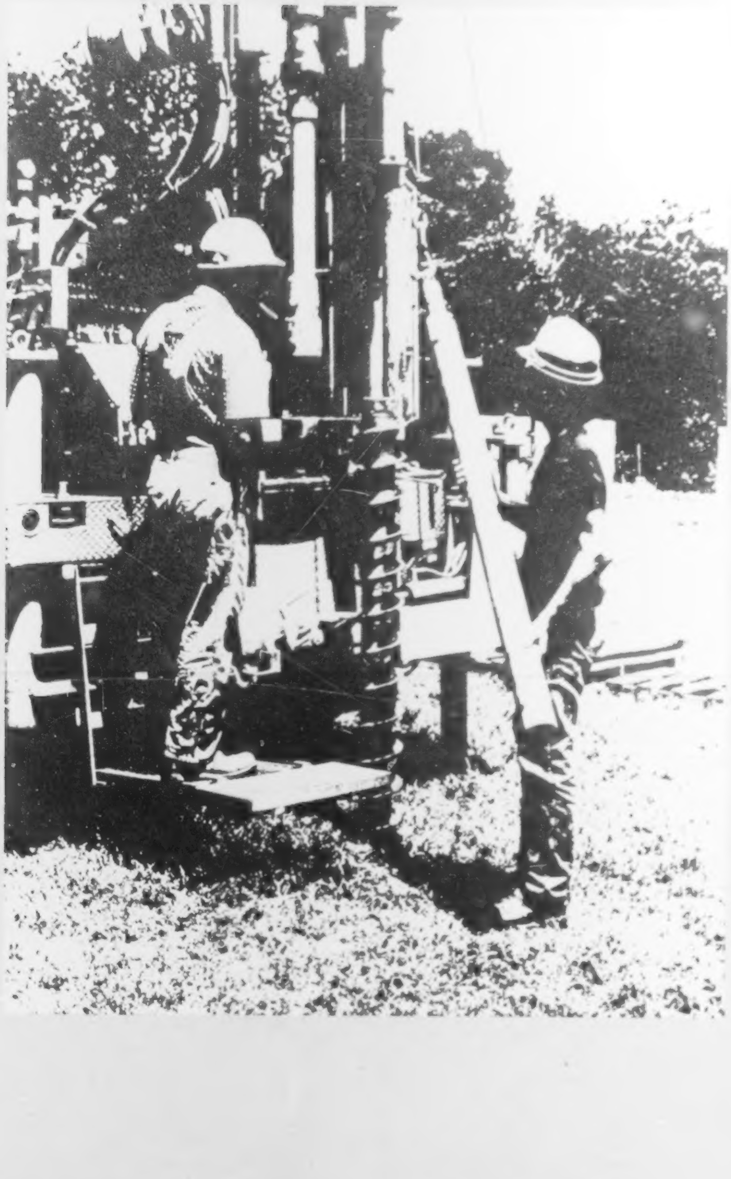
Detection



Chapter 6

Federal Efforts To Detect Groundwater Contamination

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Chapter 6

Federal Efforts To Detect Groundwater Contamination

CHAPTER OVERVIEW

This chapter describes the investigatory activities of the Federal Government related to groundwater contamination. Some of these activities are explicitly mandated by Federal legislation. Others have been undertaken by Federal agencies either to support regulatory programs or as special studies. The *techniques* used for detection activities are discussed in chapter 5.

Four major types of Federal investigatory programs are discussed:

1. conducting hydrogeologic investigations of aquifer systems, including ambient groundwater quality;
2. monitoring drinking water supply systems;
3. conducting inventories of potential sources of contamination; and
4. monitoring groundwater in the vicinity of specific sources of contamination (includes: monitoring conducted by Federal agencies with respect to federally financed remedial action programs, hydrogeologic investigations, special studies, and monitoring required under regulatory programs that apply to facility owners or operators).

These programs are providing significant information on the Nation's groundwater problems. However, their coverage is generally limited relative to the sources of contamination and substances discussed in chapter 2. For example, only recently are hydrogeologic investigations starting to look for organic chemicals; monitoring provisions for drinking water supplies address only selected substances found in public systems; inventories are conducted for only particular sources; and monitoring requirements are specified for only particular sources and their coverage is inconsistent.

The chapter begins with an overview of U.S. Geological Survey (USGS) activities. Although USGS does not have regulatory authority with respect to groundwater contamination, hydrogeologic information developed by its Water Resources Division supports the programs of other Federal agencies as well as State and local governments.

GROUNDWATER ACTIVITIES OF THE U.S. GEOLOGICAL SURVEY

Principal responsibility in the Federal Government for providing hydrogeologic information and appraising the Nation's water resources lies within the Water Resources Division of the USGS.[1] The division conducts three types of programs: 1) Federal programs, 2) the Federal-State Cooperative Program, and 3) activities for other Federal agencies.

Federal Programs

Congressional appropriations for USGS support activities on research, data collection, high-priority special topics, and coordination of Federal use and acquisition of water data.

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[1] USGS was established by legislation passed in 1879 (see 43 U.S.C. 31 et seq.). Subsequent legislation specifically authorized USGS to gauge streams and determine the Nation's water supply. For an overview of all USGS activities see Chase, et al., 1983.

Examples of programs related to groundwater quality include the Regional Aquifer-System Analysis Program, the Toxic Wastes-Groundwater Contamination Program, the Radioactive Waste Program, and the Coal Hydrology and Oil Shale Hydrology Programs. In addition, USGS maintains the National Water-Data Exchange (NAWDEX) and is involved in research efforts related to groundwater contamination (see ch. 3).

Federal-State Cooperative Program

The Federal-State Cooperative Program encompasses hydrologic data collection and water resources investigations relevant to State and local needs and issues. Congressional appropriations support the program, and the States are required to match Federal funds on a 50-50 basis. USGS considers this program "the foundation of much of the water-resources management and planning activity in the Nation and it serves as an early warning system for the detection of emerging water problems" (USGS, 1982). The program is active in all 50 States, Puerto Rico, Virgin Islands, Guam, and the Trust Territories; and during 1982, USGS had agreements with more than 800 State and local agencies (at a total funding of more than $80 million). Of these projects, 414 were at least partly related to either groundwater quality or quantity. The total budget for the groundwater portions of the investigations was $25 million (USGS, 1982; Chase, et al., 1983).

Activities for Other Federal Agencies

USGS also provides hydrologic expertise and related information to other Federal agencies upon request. The agencies are generally required to reimburse USGS. Programs established through Interagency Agreements and Memoranda of Understanding are included in this category (see ch. 3). In 1982, USGS undertook 115 projects at least partly related to groundwater for other Federal agencies. The total budget for the groundwater portion of these projects was $5.5 million (USGS, 1982).

INVESTIGATIONS OF AQUIFER SYSTEMS AND AMBIENT GROUNDWATER QUALITY

Section 104(a)(5) of the Clean Water Act specifies that EPA shall,

> . . . in cooperation with the States, and their political subdivisions, and other Federal agencies establish, equip, and maintain a water quality surveillance system for the purpose of monitoring the quality of the navigable waters and *groundwaters* . . . [emphasis added].

As noted above, USGS is responsible for collecting most of the Nation's water quality data. It operates two nationwide *surface water* monitoring programs: the National Stream Quality Accounting Network (NASQAN) and the National Hydrologic Benchmark Network.[2] Fundamental differences between surface water and groundwater have precluded the establishment of a similar nationwide program for the collection of groundwater data. For example, there is no single point in an aquifer from which "upstream" water quality can be deduced, as in river basins.

Although there is no nationwide groundwater data collection program, groundwater studies have been conducted by numerous Federal, State, and local agencies.[3] The data collected relate to site-specific conditions and the characterization of certain aquifers. Historically, the studies have focused on certain inorganic compounds; only recently have hydrogeologic investigations of specific instances of contamination started to provide some information on organic chemicals in groundwater. In recognition of these data gaps, USGS is currently involved in a program to characterize the Nation's major aquifer systems and will begin to monitor ambient groundwater in selected areas of the United States in 1984.

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[2] The NASQAN program is comprised of 504 operating stations designed to monitor the quantity and quality of water in major U.S. rivers. The National Hydrologic Benchmark Network monitors hydrologic characteristics of 52 small drainage basins that are relatively unaffected by human activities. Data collected from these programs are stored in computer systems maintained by USGS and EPA.

[3] There were 28,964 active observations by Federal agencies at groundwater stations in 1968 (see Langford, 1977). In 1982, groundwater quality data were collected at more than 7,000 stations through the Federal-State Cooperative Program and other USGS activities (see Chase, et al., 1983, p. 34).

Regional Aquifer-System Analysis Program

In 1978, USGS began a series of studies to provide basic information about certain regional groundwater systems that comprise a significant portion of the Nation's water supply. The Regional Aquifer-System Analysis (RASA) Program has identified 28 systems for possible study. Types of information being developed include: characteristics of the flow system; general water quality; regional utilization patterns; and response of aquifer systems to stress. Computer simulation models are being developed for each system to assist in understanding the natural flow regime and changes resulting from human activities and in predicting the effects of future stresses (e.g., waste disposal, artificial recharge, and pumping). The status of RASA studies as of September 1984 is shown in figure 3.

The RASA studies are conducted on a very large scale and contribute only indirectly to *site* investigations of groundwater contamination by providing a framework for model selection and analysis. Studies conducted as part of the Federal-State Cooperative program provide more detailed information about local areas within the regional systems.

Ambient Groundwater Quality Appraisal

USGS is initiating an ambient groundwater quality study that will emphasize detection of organic chemicals and trace metals. Representative areas of the United States will be selected on the basis of climate, hydrogeology, land use, and other factors. A sampling network will be designed for each area, both with samples taken first at a reconnaissance level and then at a more detailed level (Cohen, 1983).

MONITORING DRINKING WATER SUPPLIES

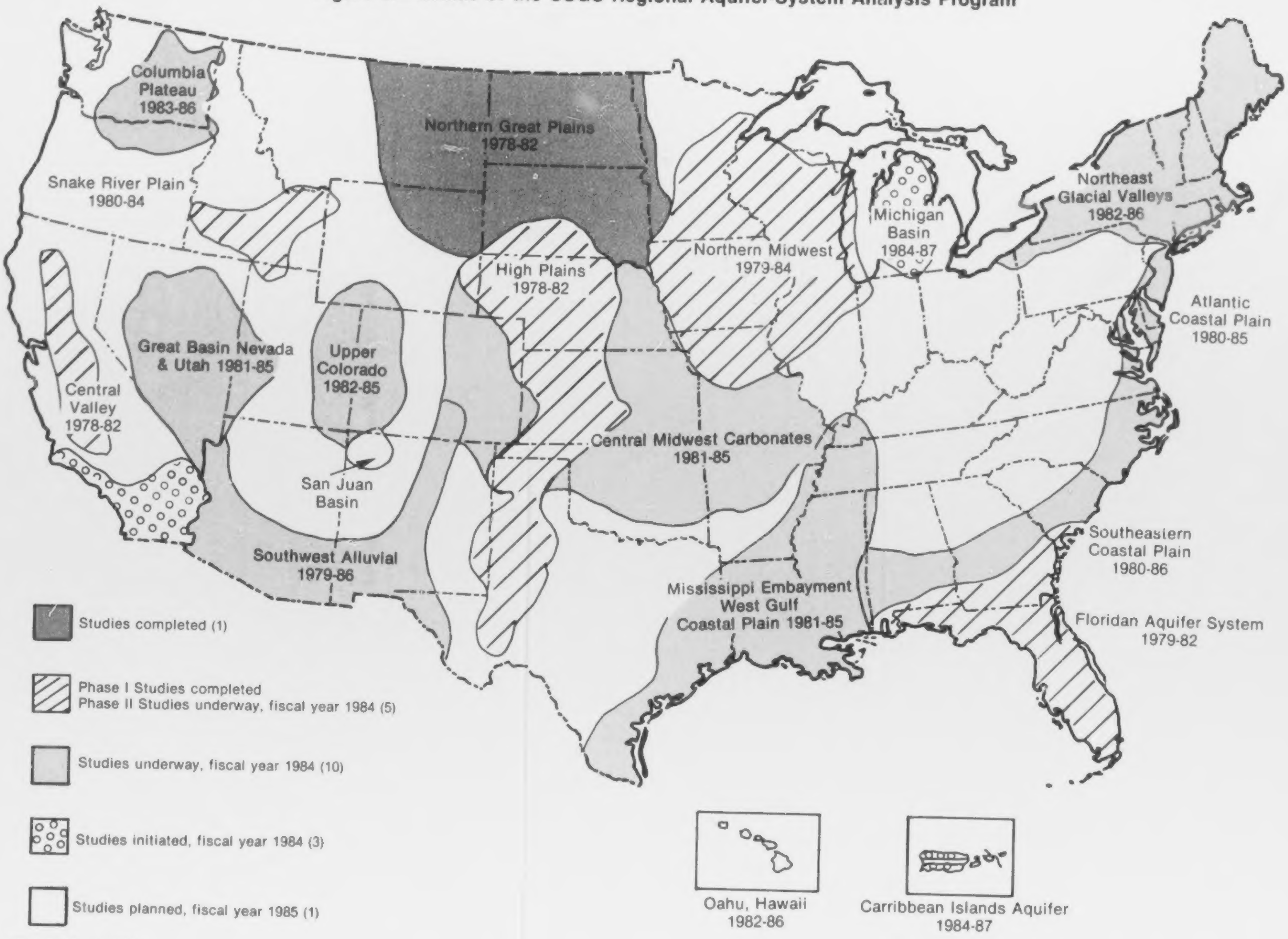
Public Water Systems

Part B of the Safe Drinking Water Act (SDWA) establishes a program to ensure that public drinking water supply systems comply with minimum national standards for substances that may adversely affect human health. The requirements apply to both surface water and groundwater. Section 1412 requires the Environmental Protection Agency (EPA) to promulgate National Drinking Water Regulations that specify either Maximum Contaminant Levels (MCLs) or treatment techniques for such substances. (See app. C.3 for a listing of standards for specific substances and other quality indicators.)

The act also provides for the establishment of an enforcement program for public water systems. Under Section 1413, a State may assume primary enforcement responsibility if it:

1. adopts drinking water regulations at least as stringent as the Federal regulations;
2. adopts and implements adequate enforcement procedures;
3. complies with EPA record-keeping and reporting requirements;
4. permits variances or exemptions based on conditions at least as stringent as the Federal requirements (Sections 1415 and 1416 of SDWA allow for variances and exemptions, respectively, from the drinking water regulations if such action would not pose an unreasonable risk to health); and
5. adopts and implements an adequate plan for provision of safe drinking water under emergency circumstances.

Figure 3.—Status of the USGS Regional Aquifer-System Analysis Program


Columbia Plateau 1983-86
Snake River Plain 1980-84
Central Valley 1978-82
Great Basin Nevada & Utah 1981-85
Upper Colorado 1982-85
San Juan Basin
Southwest Alluvial 1979-86
Northern Great Plains 1978-82
High Plains 1978-82
Central Midwest Carbonates 1981-85
Northern Midwest 1979-84
Michigan Basin 1984-87
Mississippi Embayment West Gulf Coastal Plain 1981-85
Northeast Glacial Valleys 1982-86
Atlantic Coastal Plain 1980-85
Southeastern Coastal Plain 1980-86
Floridan Aquifer System 1979-82
Oahu, Hawaii 1982-86
Carribbean Islands Aquifer 1984-87
Studies completed (1)
Phase I Studies completed
Phase II Studies underway, fiscal year 1984 (5)
Studies underway, fiscal year 1984 (10)
Studies initiated, fiscal year 1984 (3)
Studies planned, fiscal year 1985 (1)

SOURCE: Uses, 1984.

As of September 1984, 52 out of the 57 States and Territories covered by the program had accepted primacy for public water supply systems (Baltay, 1984).[4] EPA is responsible for enforcing the regulations when a State does not assume primacy.

The Safe Drinking Water Act defines a public water system as "a system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections or regularly serves at least 25 individuals."[5] **The Safe Drinking Water Act does not address individual drinking water supplies (e.g., private domestic wells).** EPA estimates that there are approximately 12-14 million individual private wells in the United States supplied by groundwater (EPA, 1983a).

Public water systems are further divided into "community" and "non-community" systems by EPA regulations.[6] "Community" systems serve at least 15 connections year-round or regularly serve at least 25 people. "Non-community" systems serve transient users, such as at highway rest stops or campgrounds, and are not required to comply with the standards for organic chemicals.[7] The States may also decide that non-community systems not be required to meet the nitrate standard; nonetheless, concentrations may not exceed a specified level.[8] A recent EPA inventory indicates that there are 59,660 community systems and approximately 160,000 non-community water supplies (Kimm, 1983).

EPA Drinking Water Surveys

EPA's Office of Drinking Water and Office of Research and Development have conducted a num-

Photo credit: State of Florida Department of Environmental Regulation

There are 12-14 million individual private wells in the United States used for drinking water; these wells are not covered by SDWA. Shown here are the pump and storage tank for a private well.

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[4] Primacy has not been accepted by the District of Columbia, Indiana, Pennsylvania, Oregon, or Wyoming (Pennsylvania is expected to do so in 1985) (Baltay, 1984). Territories under EPA jurisdiction are American Samoa, Guam, Northern Marianas, Puerto Rico, Trust Territories, and U.S. Virgin Islands.

[5] Section 1401(4), 42 U.S.C. 300(f)(4).

[6] 40 CFR 141.2(e).

[7] 40 CFR 141.12.

[8] 40 CFR 141.11(d). The water supplier must demonstrate that the water will not be available to children under the age of 6; that use of the water will not result in adverse health effects; that there will be public notification of the levels; and that the local and State officials will be notified of levels exceeding the national standard.

ber of surveys of *drinking water* supplies to provide data to support regulatory actions under SDWA (e.g., development of MCLs). These surveys include: the National Organic Reconnaissance Survey (1975, focused primarily on surface water); the National Organics Monitoring Survey (conducted 1976-77); the Rural Water Survey (conducted 1978-79); the Community Water Supply Survey (1978); and the Groundwater Supply Survey (conducted 1980-81) (see ch. 2 for additional information). EPA initiated a survey in July 1984 to collect necessary information about the nationwide occurrence of selected inorganic contaminants and radionuclides in community drinking water supplies (EPA, 1983b); results are not expected to be available before 1986 (Westrick, 1984).

SOURCE INVENTORIES

The Federal Government is also involved in investigatory efforts concerning specific sources of known or potential groundwater contamination. Activities related to the compilation of information on locations and characteristics of actual or potential sources are generally referred to as inventories. Inventories provide one indication of the extent to which particular sources are or may be contributors to contamination problems.

Federal inventory activities are of three types:

1. Federal statutes authorize the use of funds to support formal studies or projects involving the collection of information from, for example, Federal, State, and local government files and records, field investigations, and aerial photography;
2. Federal statutes or regulatory programs establish requirements for the submission of information on spills, accidents, or other releases of contaminants that have the potential to enter groundwater; and
3. Federal regulations require responsible parties to submit information about particular sources.

These inventories focus on selected sources in OTA Categories I, II, and III (namely, sources designed to discharge substances; sources designed to store, treat, and/or dispose of substances; and sources that transport or transmit substances; see ch. 2, table 5). **There are no explicit inventory provisions for sources in OTA Categories IV, V, and VI** (namely, sources discharging substances as a consequence of other planned activities; sources that provide conduits for or induce discharges of substances; and naturally occurring sources).

Formal Studies

The Resource Conservation and Recovery Act (RCRA) and the Safe Drinking Water Act (SDWA) contain provisions authorizing the use of Federal funds to conduct formal studies that involve the collection of information about particular sources—open dumps, hazardous waste sites, and surface impoundments.

Open Dumps

Section 4005(b) of RCRA requires EPA to publish an inventory of all open dumps in the United States. The States were to conduct the inventory on the basis of specific criteria developed by EPA for classifying solid waste facilities as sanitary landfills or open dumps, and the inventory was to be completed no later than 1 year after promulgation of the criteria. The criteria were published in 1979 (with subsequent amendments in 1981), almost 2 years later than the date specified by the statute.[9] EPA first published its inventory in 1981. It listed 1,209 open dumps; 80 of them were cited as having violated the groundwater requirements specified in the criteria. However, a General Accounting Office (GAO) study indicated that the 1981 inventory was based on incomplete reports from the States (GAO, 1981).

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[9] RCRA specifies that a facility may be classified as a sanitary landfill "only if there is no reasonable probability of adverse effects on health or the environment from disposal of solid waste at such facility" [42 U.S.C. 6944(a)]. Criteria established by EPA specify eight conditions that must be met by a facility in order to be classified as a sanitary landfill; one of the criteria requires that a facility not contaminate an underground drinking water source beyond the facility boundary or an alternative boundary (set on a case-by-case basis). See 40 CFR 257.3.

Photo credit: U.S. Environmental Protection Agency

Open dumps and their potential for groundwater contamination have been partially inventoried by the States but inventories have not been completed due to inadequate funding from EPA.

The inventory was published a second time in 1982, to reflect State efforts during 1981. The third edition of the inventory, published in 1983, incorporated both additions and deletions submitted by 18 States during 1982 (EPA, 1983c). The third edition contains 2,081 facilities; 130 violations of EPA's groundwater criteria were reported. EPA estimates that these figures are based on evaluation of only 3 percent of the more than 300,000 solid waste facilities in the United States (Absher, 1983).

A major problem encountered by the States with respect to completion of the inventory has been the lack of financial assistance from EPA. No Federal funds for Subtitle D programs were made available during 1982 and 1983, although funding was originally planned to extend through 1984 (EPA, 1983c).

Hazardous Waste Sites

The 1980 amendments to RCRA added Section 3012, which requires each State to, "as expeditiously as practicable, undertake a continuing program to compile, publish, and submit . . . an inventory describing the location of each site within such State at which hazardous waste has at any time been stored or disposed of."[10] Although Section 3012 also provides for Federal financial assistance to the States, funds were not appropriated until September 1982, when $10 million was appropriated from the Hazardous Substance Response Trust Fund under the Comprehensive Environmental Resource, Compensation, and Liability Act (CERCLA).[11]

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[10] 42 U.S.C. 6932.

[11] See Public Law 97-272, Appropriations Act for the Environmental Protection Agency, Sept. 30, 1982.

Funds were allocated to the States in proportion to the number of sites listed in EPA's hazardous waste site inventory as of January 17, 1983.[12]

In addition to State inventories, some Federal agencies have undertaken or have proposed inventories on Federal lands. For example, the Department of Defense conducted record searches of its installations to identify hazardous waste sites. As of August 10, 1983, 781 (out of 911) searches were completed (Daley, 1983). The Fish and Wildlife Service recently requested all field stations to inventory all lands and facilities (Hester, 1983); and the Bureau of Land Management is developing a strategy to conduct hazardous waste site inventories (Lawton, 1983).

Surface Impoundments

Section 1442(b)(3)(C) of the Safe Drinking Water Act allows EPA to award grants and enter into contracts with any public agency, educational institution, or other organization to develop and expand the capability of States and municipalities to carry out the purposes of the statute. In 1978, EPA made $5 million available to the States to conduct studies to assess the magnitude and potential effects of surface impoundments on groundwater quality. Although a draft report was issued in 1982 on the results of the assessment, a final report has not yet been issued by EPA. Subsequent drafts have been issued; the most recent is dated July 1983.

The objectives of the studies were: to locate and count the number of surface impoundments in the United States and its Territories; to provide a first approximation of the groundwater pollution potential of the impoundments; to assist the States and EPA in developing a better understanding of the problems caused by surface impoundments; and to provide a data base upon which Federal (e.g., EPA) and State authorities could develop a strategy to control or regulate pollution from these sources, including to recommend legislative programs, if necessary (EPA, 1983d).

The States located 180,973 surface impoundments used for industrial, municipal, agricultural, mining, and oil and gas extraction purposes.[13] EPA concluded from the studies that fewer than 10 percent of all sites are located in a manner that poses little threat of groundwater contamination, and approximately 85 percent of all sites are located within 1 mile of a potential surface or groundwater source (EPA, 1983d). (See ch. 2 and app. A.5 for further information on surface impoundments.)

Reporting Requirements

Four Federal statutes and their associated regulatory programs require notification of EPA or the Department of Transportation (DOT) in the event of a spill, accident, or other release of specified contaminants. The relevant statutes are the Clean Water Act and CERCLA for EPA; and the Hazardous Liquid Pipeline Safety Act (HLPSA) and the Hazardous Materials Transportation Act (HMTA) for DOT. Although reporting activities are not inventories in the strict sense, they do provide documentation on releases of substances from various sources. But, with the exception of CERCLA, **the emphasis of reporting requirements is on surface water discharges, not groundwater.** In addition, the programs address different substances; although there is some overlap, each agency has developed its own list of contaminants that it considers hazardous.

EPA Regulations: CWA and CERCLA

Section 311 of the Clean Water Act (CWA) requires individuals in charge of facilities or vessels to notify the National Response Center in the event of any discharge of oil or a hazardous substance into navigable waters, along adjoining shorelines, or into waters of the contiguous zone.[14] The National Response Center is operated by the U.S. Coast Guard in Washington, DC. Its function is to convey information about releases of oil and hazardous substances to the appropriate government agencies so that they, in turn, can determine whether and how response action should be taken.[15] Although Section 311 relates to surface water discharges, it is significant here to the extent that there may be a connection between surface water and groundwater.

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[12] 48 FR 5686.

[13] Some States also reported on other types of impoundments such as septic systems, farm ponds used for stock watering, and safety impoundments around bulk storage tanks.

[14] Section 311(b)(2)(A) requires EPA to promulgate regulations listing the hazardous substances that are subject to this section. These substances are listed in 40 CFR 116. Section 311(b)(4) requires the determination of quantities of oil and hazardous substances, discharge of which may be harmful to public health or welfare. 40 CFR 117 specifies the quantities.

[15] 40 CFR 300.36.

CERCLA contains a provision that is similar to Section 311 of CWA, but it is explicitly applicable to groundwater as well as surface water. Section 103(a) requires individuals in charge of facilities or vessels to notify the National Response Center in the event of *any* release of any hazardous substances in quantities equal to or greater than specified amounts.[16] The definition of the term "release" encompasses: spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment.[17] In addition, Section 103(c) of CERCLA required individuals to notify EPA of the existence of any unauthorized hazardous waste facilities by June 1981. The sites identified are part of EPA's inventory of hazardous waste sites.

DOT Regulations: HLPSA and HMTA

Under regulations promulgated by DOT for pipelines and transportation-related sources, all carriers are required to submit written reports to DOT describing any accidents within 15 days of their discovery. DOT prepares annual reports which summarize the information reported under these regulations. (See app. A.5 for data on numbers of accidents from these reports.)

DOT regulations under HLPSA specify that any failure in a pipeline system must be reported if the release of a hazardous liquid (defined as petroleum, petroleum products, or anhydrous ammonia) results in: 1) an explosion or fire not intentionally set by the operator; 2) loss of 50 or more barrels of liquid; 3) escape to the atmosphere of more than 5 barrels a day of highly volatile liquids; 4) the death of anyone; 5) bodily harm to anyone; or 6) estimated damage to the property of the operator or others, or both, exceeding $5,000.[18] In cases of significant damage, DOT must be notified immediately by telephone. Criteria for such instances include, but are not limited to, accidents resulting either in damage exceeding $5,000 (as above) or in the "pollution of any stream, river, lake, reservoir, or other similar body of water that violated applicable water quality standards, caused discoloration of the surface of the water or adjoining shoreline, or deposited a sludge or emulsion beneath the surface of the water or on adjoining shorelines."[19] Similar conditions for groundwater are not specified.

DOT regulations for HMTA contain similar provisions. The hazardous materials coverage is extensive.[20] DOT must be notified by telephone at the earliest practicable moment after any incident in which: 1) a person is killed; 2) a person receives injuries requiring hospitalization; 3) estimated damage to the carrier or other property exceeds $50,000; 4) fire, breakage, spillage, or suspected radioactive contamination involving shipment of radioactive material occurs; 5) fire, breakage, spillage, or suspected contamination involving shipment of etiologic agents occurs; or 6) in the judgment of the carrier, the situation should be reported.[21] In the event of a discharge of a reportable quantity of a hazardous substance into navigable waters or along adjacent shorelines, the National Response Center must be notified (see the discussion under CWA above). As is true for the pipeline requirements, no reporting requirements are tied to groundwater contamination other than the property damage provisions.

Regulatory Requirements Related to Inventories

Part C of SDWA requires EPA to establish regulations specifying minimum requirements for State Underground Injection Control (UIC) Programs.

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[16] Under CERCLA, the term "hazardous substances" includes those substances covered by Sections 311(b)(2)(A) and 307(a) of CWA, Section 102 of CERCLA, Section 3001 of RCRA, Section 112 of the Clean Air Act, and Section 7 of TSCA. Section 102(a) of CERCLA requires EPA to designate hazardous substances (in addition to those specified above) and to establish reportable quantities for them. Section 102(b) specifies that a reportable quantity of 1 pound shall apply to all the hazardous substances included in the statutes listed above (except for different quantities established under Section 311(b)(4) of CWA) unless and until EPA establishes reportable quantity regulations pursuant to Section 102(a).

[17] Section 101(22).

[18] 49 CFR 195.50. A special accident reporting form has been developed by DOT (DOT Form 7000-1).

[19] 49 CFR 195.52(a).

[20] See 49 CFR 172.

[21] 49 CFR 171.15. DOT Form F 5800.1 must also be submitted within 15 days of discovery of the accident (see 49 CFR 171.16).

Final Federal regulations were published on February 3, 1982, and the States are now in the process of developing UIC programs based on these requirements. The States are required to establish a permitting program for injection wells. Most existing wells are authorized by rule until a State program is in place and site-specific permits are issued. One section of the Federal regulations requires owners and operators of injection wells authorized by rule to submit inventory information to the States or EPA about their operations within one year after they are authorized. The inventory form requires information on the facility name and location, a legal contact, ownership, the nature and type of wells, and the operating status of the wells.[22]

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[22] 40 CFR 144.26.

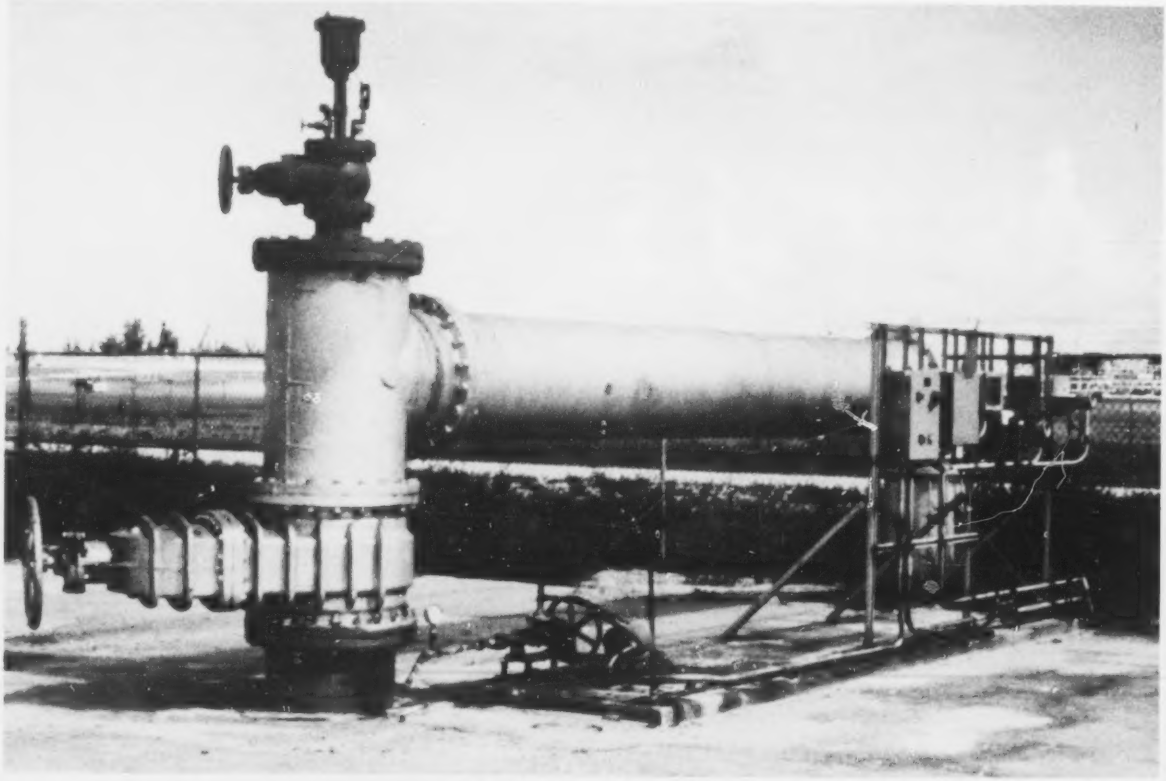

Photo credit: State of Florida Department of Environmental Regulation

Permitting rules developed under State Underground Injection Control Programs typically address the construction and monitoring of injection wells.

GROUNDWATER MONITORING AND SOURCES

This section summarizes Federal efforts related to monitoring specific sources of groundwater contamination. Three types of monitoring activities are discussed:

1. monitoring requirements specified by Federal regulations that apply to facility owners and operators;
2. monitoring conducted by Federal agencies relative to federally funded remedial programs; and
3. monitoring conducted by Federal agencies as part of hydrogeologic investigations related to certain sources.

Table 30 summarizes these groundwater monitoring activities as they relate to Federal statutes and indicates the objectives of each program. Appendix E contains more detailed information about these activities for each source. In addition to the statutory provisions shown in table 30, other Federal groundwater monitoring activities are also described below.

In summary, Federal monitoring requirements are specified for certain sources in OTA Categories I, II, IV, and V (see ch. 2, table 5). But there are inconsistencies in the coverage of the monitoring provisions for similar sources under different programs. Detailed guidance on the design of site-specific monitoring systems is not provided in the regulations. Although guidance manuals have been developed by some agencies, the individuals who draft and review permits (including exemptions) are responsible for ensuring the adequacy of site-specific systems; adequately trained personnel are in short supply. A detailed discussion of these conclusions follows.

Monitoring Provisions of Federal Programs

There are 10 regulatory programs authorized by Federal statutes that establish groundwater monitoring provisions for sources of contamination. However, these **programs address only certain sources in OTA Categories I, II, IV, and V, and monitoring is not *required* for many of them.** For example, there are no requirements for non-point sources in Category IV such as irrigation practices and fertilizer applications. **Groundwater monitoring requirements are not established for any sources in Categories III and VI.**

In addition, **monitoring requirements for sources within the same category are not uniform.** Under the Toxic Substances Control Act (TSCA), for example, required groundwater monitoring for PCB disposal sites is limited to an initial collection of background data. In contrast, the regulations promulgated for radioactive disposal sites under the Atomic Energy Act (AEA) and for hazardous waste sites under the Resource Conservation and Recovery Act (RCRA) require monitoring during operation and after closure.

For the most part, *final* Federal regulations do not contain explicit monitoring requirements (e.g., numbers and locations of wells) in recognition of the site-specific nature of groundwater contamination problems and the technical uncertainties associated with hydrogeologic investigations (see ch. 5). Because of the variety and complexity of factors that must be considered in designing a program to monitor (e.g., sample and analyze) groundwater quality, Federal regulations establish monitoring objectives and general guidelines rather than detailed requirements.[23]

In the absence of detailed monitoring requirements, several Federal agencies have developed manuals to assist both permit (or license) writers and the regulated community.[24] The manuals provide guidance on determining background levels, selecting parameters, designing a monitoring network (e.g., number and location of wells), selecting appropriate sampling frequencies, and other topics. Because monitoring programs do not specify detailed requirements, the burden of ensuring that

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[23] See e.g., Final NRC Regulations for Low Level Radioactive Waste Disposal Facilities, 47 FR 57452, Dec. 27, 1982; Final OSM Regulations for Surface Coal Mining and Reclamation Operations, 48 FR 43974, Sept. 26, 1983; and Final EPA Regulations for Hazardous Waste Land Disposal Facilities, 47 FR 32274, July 26, 1982.

[24] For example, see EPA, 1983e,, 1983f; and NRC, 1983a, 1983b.

Table 30.—Federal Groundwater Monitoring Provisions and Objectives

Statutory authority	Monitoring provisions[a]	Monitoring objectives
Atomic Energy Act	Groundwater monitoring is specified in Federal regulations for low-level radioactive waste disposal sites. The facility license must specify the monitoring requirements for the source. The monitoring program must include: —Pre-operational monitoring program conducted over a 12-month period. Parameters not specified. —Monitoring during construction and operation to provide early warning of releases of radionuclides from the site. Parameters and sampling frequencies not specified. —Post-operational monitoring program to provide early warning of releases of radionuclides from the site. Parameters and sampling frequencies not specified. System design is based on operating history, closure, and stabilization of the site.	To obtain background water quality data and to evaluate whether groundwater is being contaminated.
	Groundwater monitoring related to the development of geologic repositories will be conducted. Measurements will include the rate and location of water inflow into subsurface areas and changes in groundwater conditions.	To confirm geotechnical and design parameters and to ensure that the design of the geologic repository accommodates actual field conditions.
	Groundwater monitoring may be conducted by DOE, as necessary, part of remedial action programs at storage and disposal facilities for radioactive substances.	To characterize a contamination problem and to select and evaluate the effectiveness of corrective measures.
Clean Water Act —Sections 201 and 405	Groundwater monitoring requirements are established on a case-by-case basis for the land application of wastewater and sludge from sewage treatment plants.	To evaluate whether groundwater is being contaminated.
—Section 208	No explicit requirements are established; however, groundwater monitoring studies are being conducted by SCS under the Rural Clean Water Program to evaluate the impacts of agricultural practices and to design and determine the effectiveness of Best Management Practices.	To characterize a contamination problem and to select and evaluate the effectiveness of corrective measures.
Coastal Zone Management Act	The statute does not authorize development of regulations for sources. Thus, any groundwater monitoring conducted would be the result of requirements established by a State plan (e.g., monitoring with respect to salt-water intrusion) authorized and funded by CZMA.	
Comprehensive Environmental Response, Compensation, and Liability Act	Groundwater monitoring may be conducted by EPA (or a State) as necessary to respond to releases of any hazardous substance, contaminant, or pollutant (as defined by CERCLA).	To characterize a contamination problem (e.g., to assess the impacts of the situation, to identify or verify the source(s), and to select and evaluate the effectiveness of corrective measures).
Federal Insecticide, Fungicide, and Rodenticide Act—Section 3	No monitoring requirements established for pesticide users. However, monitoring may be conducted by EPA in instances where certain pesticides are contaminating groundwater.[b]	To characterize a contamination problem.
Federal Land Policy and Management Act (and Associated Mining Laws)	Groundwater monitoring is specified in Federal regulations for geothermal recovery operations on Federal lands for a period of at least one year prior to production. Parameters and monitoring frequency are not specified.	To obtain background water quality data.
	Explicit groundwater monitoring requirements for mineral operations on Federal lands are not established in Federal regulations. Monitoring may be required (as a permit condition) by BLM.	
Hazardous Liquid Pipeline Safety Act	Although the statute authorizes development of regulations for certain pipelines for public safety purposes, the regulatory requirements focus on design and operation and do not provide for groundwater monitoring.	
Hazardous Materials Transportation Act	Although the statute authorizes development of regulations for transportation for public safety purposes, the regulatory requirements focus on design and operation and do not provide for groundwater monitoring.	
National Environmental Policy Act	The statute does not authorize development of regulations for sources.	
Reclamation Act	No explicit requirements established; however, monitoring may be conducted, as necessary, as part of water supply development projects.	
Resource Conservation and Recovery Act	Groundwater monitoring is specified in Federal regulations for all hazardous waste land disposal facilities (e.g., landfills, surface impoundments, waste piles, and land treatment units).	

Table 30.—Federal Groundwater Monitoring Provisions and Objectives—continued

Statutory authority	Monitoring provisions[a]	Monitoring objectives
Resource Conservation and Recovery Act (cont'd) —Subtitle C	*Interim Status* monitoring requirements must be met until a final permit is issued. These requirements specify the installation of at least one upgradient well and three downgradient wells. Samples must be taken quarterly during the first year and analyzed for the National Interim Drinking Water Regulations, water quality indicator parameters (chloride, iron, manganese, phenols, sodium, and sulfate), and indicator parameters (pH, specific conductance, TOC, and TOX). In subsequent years, each well is sampled and analyzed quarterly for the six background water quality indicator parameters and semiannually for the four indicator parameters. *Groundwater monitoring requirements can be waived* by an owner/operator if a written determination indicating that there is low potential for waste migration via the upper-most aquifer to water supply wells or surface water is made and certified by a qualified geologist or engineer. The determination is not submitted to EPA for verification or approval.	To obtain background water quality data and evaluate whether groundwater is being contaminated.
	The monitoring requirements for a *fully permitted* facility are comprised of a three-part program:	To obtain background water quality data or evaluate whether groundwater is being contaminated (detection monitoring), to determine whether groundwater quality standards are being met (compliance monitoring), and to evaluate the effectiveness of corrective action measures.
	—*Detection Monitoring* — Implemented when a permit is issued and there is no indication of leakage from a facility. Parameters are specified in the permit. Samples must be taken and analyzed at least semiannually. *Exemptions* from detection monitoring program may be granted by the regulatory authority for landfills, surface impoundments, and waste piles with double liners and leak detection systems. —*Compliance Monitoring* — Implemented when groundwater contamination is detected. Monitoring is conducted to determine whether specified concentration levels for certain parameters are being exceeded (levels are based on background concentrations, maximum contaminant levels specified by the National Drinking Water Regulations [if higher than background], or an alternative concentration limit [established on a site-specific basis]). Samples must be taken and analyzed at least quarterly for parameters specified in the permit. Samples must also be analyzed for a specific list of 375 hazardous constituents (Appendix VIII, 40 CFR 261) at least annually. —*Corrective Action Monitoring* — Implemented if compliance monitoring indicates that specified concentration levels for specified parameters are being exceeded (and corrective measures are required). Monitoring must continue until specified concentration levels are met. Parameters and monitoring frequency not specified. —Exemption from groundwater monitoring requirements may be granted by the regulatory authority if there is no potential for migration of liquid to the uppermost aquifer during the active life and closure and post-closure periods.	
—Subtitle D	Groundwater monitoring may be required by State solid waste programs. Federal requirements for State programs *recommend* the establishment of monitoring requirements.	
Safe Drinking Water Act —Part C—Underground Injection Control Program	Groundwater monitoring requirements may be specified in a facility permit for injection wells used for in-situ or solution mining of minerals (Class III wells) where injection is into a formation containing less than 10,000 mg/l TDS. Parameters and monitoring frequency not specified except in areas subject to subsidence or collapse where monitoring is required on a quarterly basis. Groundwater monitoring may also be specified in a permit for wells which inject beneath the deepest underground source of drinking water (Class I wells). Parameters and monitoring frequency not specified in Federal regulations.	To evaluate whether groundwater is being contaminated.

Table 30.—Federal Groundwater Monitoring Provisions and Objectives—continued

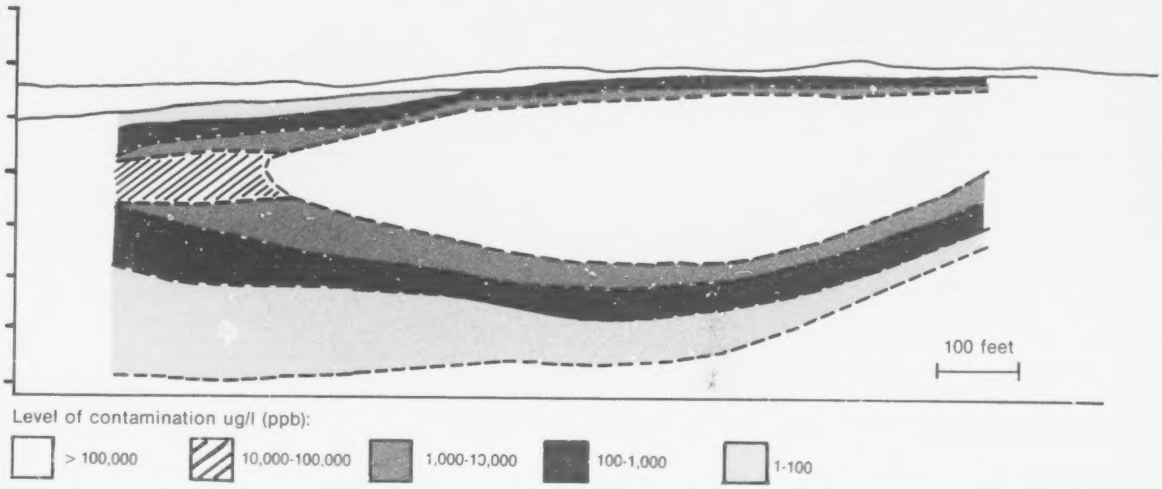
Statutory authority	Monitoring provisions	Monitoring objectives
Surface Mining Control and Reclamation Act	Groundwater monitoring is specified in Federal regulations for surface and underground coal mining operations to determine the impacts on the hydrologic balance of the mining and adjacent areas. A groundwater monitoring plan must be developed for each mining operation (including reclamation). At a minimum, parameters must include total dissolved solids or specific conductance, pH, total iron, and total manganese. Samples must be taken and analyzed on a quarterly basis. *Monitoring of a particular water-bearing stratum may be waived by* the regulatory authority if it can be demonstrated that it is not a stratum which serves as an aquifer that significantly ensures the hydrologic balance of the cumulative impact area.	To obtain background water quality data and evaluate whether groundwater is being contaminated.
Toxic Substance Control Act —Section 6	Groundwater monitoring specified in Federal regulations requires monitoring prior to commencement of disposal operations for PCBs. Only three wells are required if underlying earth materials are homogenous, impermeable and uniformly sloping in one direction. Parameters include (at a minimum) PCBs, pH, specific conductance, and chlorinated organics. Monitoring frequency not specified. No requirements are established for active life or after closure.	To obtain background water quality data.
Uranium Mill Tailings Radiation Control Act	Federal regulatory requirements for active mill tailings sites are, for the most part, the same as those established under Subtitle C of RCRA.[c]	To obtain background water quality data, evaluate whether groundwater is being contaminated, determine whether groundwater quality standards are being met, and evaluate the effectiveness of corrective action measures.
	Groundwater monitoring for inactive sites may be conducted if necessary to determine the nature of the problem and for the selection of an appropriate remedial action.	To obtain background water quality data and to characterize a contamination problem.
Water Research and Development Act	The statute does not authorize the development of regulations for sources. Groundwater monitoring may be conducted as part of projects funded by the act.	

[a] The monitoring provisions presented in this table are either: those specified by regulations for existing and new sources; or for groundwater monitoring that may be conducted as part of an investigatory study or remedial action program.

[b] Pesticide manufacturers may be required by EPA to submit groundwater monitoring data as part of the registration requirements for a pesticide product to evaluate the potential for a pesticide to contaminate groundwater.

[c] See app. E.2 for a summary of the differences between UMTRCA and RCRA monitoring requirements.

SOURCE: Office of Technology Assessment.



Credit: Tewhey, et al., 1982

The site-specific nature of groundwater contamination problems requires that hydrogeologic investigations be tailored to site conditions. At this site, the design of the monitoring system provided data that were used for determining the vertical distribution of volatile organic chemicals.

site-specific monitoring satisfies program objectives lies with the individuals responsible for drafting and approving facility permits and licenses.

Although monitoring requirements generally lack specificity, some Federal regulations contain more detailed requirements than others. For example, the regulations developed under the Surface Mining Control and Reclamation Act (SMCRA) and TSCA specify the minimum parameters that must be measured; and RCRA (Subtitle C), the Safe Drinking Water Act, SMCRA, and the Uranium Mill Tailings Radiation Control Act (UMTRCA) specify monitoring frequencies. In addition, the number of monitoring wells is specified in both the requirements for PCB disposal sites under TSCA and the *interim status* requirements under Subtitle C of RCRA.

OTA's study did not focus on the implementation of Federal regulations (see OTA, forthcoming). A recent General Accounting Office (GAO) study of the RCRA *interim status* program in four States indicates a substantial amount of non-compliance with the groundwater monitoring requirements (GAO, 1983). For example, in two of the four States, 78 percent of the facilities required to conduct groundwater monitoring were not in compliance with the regulations (e.g., monitoring wells were lacking and wells were not sited correctly). Some of the non-compliance was related to the technical complexities of locating and constructing wells and the costs of well installation, sampling, and analysis. The States also cited a number of problems regarding enforcement of the RCRA regulations: lack of resources (e.g., staff); lack of technical expertise and guidance; and confusion among State agencies about jurisdiction over facility inspections.

As indicated in table 30, the interim status requirements (which specify the number of monitoring wells) must be met by hazardous waste land disposal facilities until a final permit is approved either by the Environmental Protection Agency (EPA) or a State with an EPA-approved RCRA program. EPA estimates that it will take approximately 10 years to review and approve permits for an estimated 1,350 land disposal facilities nationwide (GAO, 1983).

Certain facilities are exempted from groundwater monitoring requirements. The exemption or waiver provisions noted below provide varying degrees of guidance for making exceptions on a site-by-site basis:

- Under the SMCRA regulations for coal mining, monitoring of a water-bearing stratum may be waived by the regulatory authority if it is determined that the stratum is not an aquifer that significantly ensures the hydrologic balance of the "cumulative impact area."[25] The waiver determination is based on information developed as part of an assessment (referred to as a "probable hydrologic consequences determination") regarding whether the mining operation will adversely affect the hydrologic balance; cause surface or groundwater contamination; and affect groundwater availability, water quality, or a variety of other factors.[26]

- Under the RCRA Subtitle C *interim status* program, owners and operators of land disposal facilities can waive groundwater monitoring requirements if they obtain a written determination, certified by a qualified geologist or geotechnical engineer, that there is low potential for water migration from the facility via the uppermost aquifer to water supply wells or surface water. The waiver document is retained at the facility; it is not submitted to EPA for review until the facility is called in for final permit review, which may be as long as 10 years. The evaluation of the potential for migration must be based on an assessment of the water balance, unsaturated and saturated zone characteristics, and proximity of the facility to water supply wells or surface water.[27]
- RCRA Subtitle C regulations for *fully permitted* land disposal facilities also contain exemption provisions. Groundwater monitoring may be waived by the regulatory authority for facilities if it is determined that there is no potential for migration of liquids to the uppermost aquifer during active, closure, and postclosure periods. Any predictions made about migration potential must be based on assumptions that maximize the rate of liquid migration.[28] In addition, at landfills, surface impoundments, and waste piles where double liners and leak detection systems are installed, exemptions from the detection monitoring program may be granted. A previous OTA study of the hazardous waste land disposal technologies specified in the RCRA regulations concluded that the lack of groundwater monitoring at double-lined facilities does not protect groundwater because such systems are not failsafe (OTA, 1983).

Monitoring and Remedial Action Programs

In addition to the monitoring requirements described in the previous section, groundwater monitoring may also be conducted as part of a federally funded remedial action effort—e.g., to characterize a contamination problem and to evaluate and select among alternative corrective measures.

Table 30 indicates that monitoring is addressed by programs authorized by AEA, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and UMTRCA. Like the requirements discussed above for permitted or licensed facilities, explicit groundwater monitoring requirements are not specified under these programs. Such an approach is consistent with the site-specific nature of groundwater contamination problems.

Other Monitoring Activities

A number of Federal agencies are undertaking additional groundwater monitoring programs with

Photo credit: U.S. Environmental Protection Agency

Hydrogeologic investigations, including soil testing as shown, provide important input to the evaluation and selection of corrective actions.

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[25] The cumulative impact area is the area within which the proposed mining operation may interact with all other anticipated mining. (30 CFR 701.5, 48 FR 43985, Sept. 26, 1983).

[26] See 30 CFR 780.21, 48 FR 43985, Sept. 26, 1983. The regulations specify the types of information that must be submitted to support this.

[27] 40 CFR 265.90(c).

[28] 40 CFR 264.90(b)(4).

respect to specific sources of contamination. **Some of this work focuses on some of the sources in Categories IV and VI for which no monitoring requirements are established (e.g., fertilizer applications, animal feeding operations, and natural leaching).**

Additional monitoring has been undertaken by the following Federal agencies:

- The Soil Conservation Service (SCS), in conjunction with the States, private institutions, and other Federal agencies such as the Agricultural Stabilization and Conservation Service, is involved with several contamination investigations under the Rural Clean Water Program authorized by Section 208(j) of the Clean Water Act relating to agricultural operations (table 30). The groundwater data being collected will be used to support the development of Best Management Practices.[29]
- EPA's Office of Pesticide Programs has been involved with several groundwater monitoring studies. For example, the office conducted monitoring studies where contamination from pesticide applications was detected. The studies focused on aldicarb and DBCP. In addition, EPA has been evaluating groundwater quality and the fate and transport of pesticides in several States (e.g., Wisconsin, Georgia, and California) in conjunction with the States, local governments, universities, and other Federal agencies (e.g., USGS). The studies focus on those pesticides used in each State that, based on their chemical properties, have the greatest potential to leach into groundwater (Severn, et al., 1983). EPA and other Federal agencies have been working together on monitoring related to the formulation and implementation of the National Pesticide Monitoring Plan (NPMP) under the Federal Insecticide, Fungicide, and Rodenticide Act.[30] A program directed exclusively at groundwater, however, has not been implemented.[31]
- The Bureau of Reclamation, in conjunction with SCS and USGS, is participating in monitoring efforts as part of the Colorado River Basin Salinity Control Program.[32] The sources of contamination are underlying geologic formations containing salts, which are being leached due to infiltration of excessive amounts of irrigation water. The groundwater data collected will be used in the development of irrigation water management strategies.
- USGS has programs devoted to three specific sources of groundwater contamination: 1) coal and oil shale development, 2) radioactive waste disposal, and 3) toxic waste disposal (see preceding section on *Federal Programs*) Each involves groundwater monitoring. For example, as part of the coal and oil shale programs, USGS is collecting data at thousands of mining areas. Under the Toxic Wastes-Groundwater Contamination Program, field investigations are being conducted on the mobility and fate of organic substances in groundwater.[33]

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[29] One study in Lancaster County, PA, is concerned with contamination resulting from sources such as animal wastes and fertilizer and pesticide applications. Groundwater is being monitored to establish background levels and to assess the impacts of the Best Management Practices (USDA, 1982). A similar study is being undertaken in eastern South Dakota (South Dakota State Coordinating Committee, 1982).

[30] Section 20(b) and (c).

[31] For additional discussion about the NPMP see National Research Council, 1978.

[32] The Colorado River Basin Salinity Control Act of 1974 (Public Law 93-320) authorizes construction, operation, and maintenance, of certain works to control water salinity in the Colorado River Basin. The program is extensive, covering seven States (California, Arizona, New Mexico, Colorado, Nevada, Utah, and Wyoming) divided into numerous units. Other Federal agencies such as the Agricultural Stabilization and Conservation Service, EPA, the Bureau of Land Management, and the Fish and Wildlife Service are involved in various aspects of the project. As an example, see DOI, 1983.

[33] See Chase, et al., 1983.

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Chapter 7

State Efforts To Detect Groundwater Contamination

CHAPTER OVERVIEW

In this chapter, State responses to survey questions about their efforts to detect groundwater contamination are presented. (See the section *OTA State Survey* in ch. 4 for guidance in interpreting survey results.) The following topics are discussed:

- sources of groundwater contamination for which the States have detection programs;
- State inventory and monitoring activities;
- formal procedures for monitoring; and
- State use, preferences, and problems with techniques for hydrogeologic investigations.

Additional information on State strengths, problems, and types of desired Federal assistance related to detection is found in chapter 4. The *techniques* used for detection activities are discussed in chapter 5.

The conclusions drawn in this chapter follow.

The States are working to detect contamination principally through inventories, source monitoring, water supply monitoring, and ambient water quality monitoring. Inventory and monitoring efforts are focused on point sources related to waste disposal and large public water supplies. Not all potential sources of contamination of water supplies are being monitored.

Most States are working to improve monitoring and detection but are constrained primarily by institutional or technical factors often related to funding (e.g., technical expertise, manpower, availability of equipment, and the high cost of applying available technology). The States also experience technical constraints in conducting hydrogeologic analyses because of the uncertainties inherent in groundwater contamination investigations (see ch. 5).

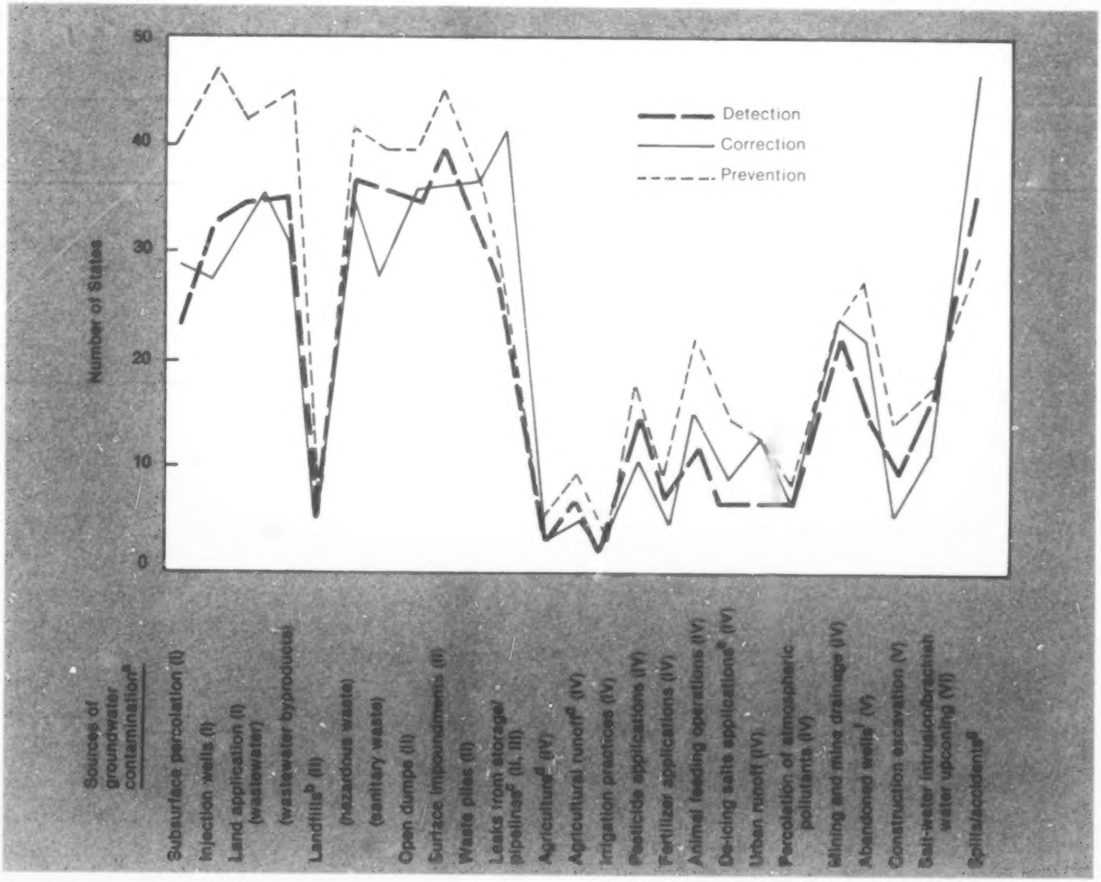
State detection programs are, for the most part, in the early stages of development. Some States have made more progress than others. Much of the activity is handled on an ad hoc case-by-case basis, relying on the best professional judgment of staff. This practice is somewhat troublesome for the States because many have difficulty attracting and retaining staff with sufficient technical expertise.

All but five States perceive weaknesses with their detection programs or opportunities for Federal assistance in this area including: funding, technical assistance, and research and development, as discussed in chapter 4.

STATE DETECTION PROGRAMS FOR SOURCES OF CONTAMINATION

Many States have detection programs for a variety of sources, as shown in figure 4. The highest number of States have programs to detect contamination from surface impoundments and landfills (both hazardous and sanitary). Generally, more State programs are associated with OTA source Categories I, II, and III than with IV, V, and VI. These programs involve primarily *inventory* activities or actual *monitoring* of groundwater quality and are discussed in the next section. Other detection activities would include *inventory control* (i.e., accounting for all material) and/or *testing* the integrity of facilities.

Figure 4.—OTA State Survey Responses: Number of States With Programs To Detect Groundwater Contamination From Selected Sources



See fig. 2 for footnotes a through g.

SOURCE: Office of Technology Assessment.

STATE INVENTORY AND MONITORING ACTIVITIES

State Inventory Activities

Inventories are used primarily to locate sites or facilities with the potential to contaminate groundwater. A few States have conducted inventories of substances used in the States that could potentially contaminate groundwater (e.g., pesticides, herbicides, and hazardous substances). Specific contamination incidents are also recorded by some States; this information can assist in identifying potential problem sources:

- Forty-seven States conduct inventories of potential sources of contamination. As shown in table 31, the States have inventoried different sources. Most of these efforts have not been comprehensive, i.e., many potential sources of contamination identified by OTA's analysis have not been inventoried.

Table 31.—OTA State Survey Responses: Number of States Conducting Inventories and Monitoring Different Categories of Sources of Potential Groundwater Contamination

Source category[a]	Inventories	Source monitoring
I— Sources designed to discharge substances[b]	26	27
II— Sources designed to store, treat, and/or dispose of *wastes*[c]	37	42
II— Sources designed to store *non-wastes*[d]	8	3
III— Sources designed to transport or transmit substances[e]	1	0
IV— Sources that discharge substances as a consequence of other planned activities[f]	6	10
V— Sources that provide a conduit[g]	2	0
VI— Naturally occurring sources[h]	1	3
Not specified	6	4
None	3	1
Total number of States	47	49

[a] The States did not use consistent terminology in response to questions about their inventory and monitoring activities; responses were classified according to OTA source categories (see ch. 2). Examples of the various types of State responses included in each category are listed in the respective footnotes.

[b] Underground injection wells, surface treatment and disposal systems, wastewater disposal, septic systems, sludge disposal, and drainage wells.

[c] Industrial waste management areas, hazardous waste sites, municipal waste sites, lagoons, waste treatment systems, open dumps, landfills, waste storage ponds, and RCRA sites.

[d] Underground storage tanks, salt storage, and industrial sites.

[e] Transportation facilities.

[f] Urban development, agricultural practices, oil and gas development-related sources, and mining operations.

[g] Wells, springs, and active and abandoned wells.

[h] Natural contamination and salt-water intrusion.

SOURCE: Office of Technology Assessment.

- The highest number of States inventory Category II sources (designed to store, treat, and/or dispose of substances). Within this category, inventories are concentrated on waste-related facilities. More than one-half the States also inventory Category I sources (designed to discharge substances). Relatively few States have conducted inventories of sources in other OTA categories.

State Monitoring Activities

Having identified potential sources of contamination and, in some cases, substances that are potential contaminants, the States may monitor to determine whether groundwater is actually contaminated. Monitoring may be directed at various points of concern: potential sources, water supplies, and ambient conditions.

Monitoring Potential Sources of Contamination

- Forty-nine States monitor sources for potential contamination. Most of these efforts focus on Category II waste-related facilities or on other permitted or licensed activities, including many Category I sources, as shown in table 31.
- Monitoring potential sources of contamination is generally *not* comprehensive. All facilities and activities of a particular source type are not monitored, and some sources are not monitored at all. For example, four States monitor only selected facilities within various source categories, and one State monitors only permitted or licensed facilities. Sources that are not monitored by at least one State include: direct discharges to groundwater through sinkholes, abandoned hazardous waste sites that are not currently eligible for corrective action funding under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and many abandoned solid waste sites.
- The sources of priority concern vary among the States. The highest number of States give priority to Category II sources, particularly hazardous waste sites and substances and landfills.

Monitoring Water Supplies:

- All public drinking water supplies are monitored for compliance with the Safe Drinking Water Act. Ten States monitor private wells either on request or in relation to potential sources of contamination. Few States monitor industrial water supplies (three) or agricultural supplies (two).
- In general, priority is given to public drinking water supplies. The attention given to monitoring private wells and non-drinking water supplies varies. One State gives priority to private wells and one State to supplies other than drinking water.

Monitoring Ambient Quality

- In general, 38 States monitor ambient groundwater quality or are in the process of developing such programs. These programs include: relying on U.S. Geological Survey (USGS) monitoring of wells; limited monitoring of new wells; monitoring for background quality only in relation to permit activities; using a statewide monitoring network; or monitoring special sites or regions of concern. Most State ambient quality monitoring to ascertain existing groundwater contamination appears limited.

- Nine States rely on USGS monitoring programs for information about ambient water quality. However, USGS recognizes that these are inadequate to detect contamination from organic substances and trace metals and to provide information on key chemical parameters such as dissolved oxygen and microbial activity (Cohen, 1983).[1]
- Eight States are in the process of developing monitoring programs to improve their information on ambient quality. For example, one State is planning to expand monitoring for pesticides and radiological substances, particularly in more densely populated areas.
- Only one State explicitly reported having a statewide groundwater monitoring network. One State has an ambient water quality network for the most populous part of the State. Another monitors selected areas with suspected or known groundwater quality problems. Four other States focus on particular sites or regions of concern.

Photo credit: U.S. Geological Survey

USGS personnel have routinely collected information on water levels, total dissolved solids, and many inorganic chemicals in monitoring wells throughout the country. However, information has not been collected routinely on organic substances, trace metals, and other key chemical parameters.

FORMAL PROCEDURES FOR MONITORING

Detection programs involving groundwater monitoring require the systematic collection and analysis of a great deal of technical data, as discussed in chapter 5. The OTA survey asked the States about their use of formal policies, procedures, and guidelines for obtaining groundwater quality information and using monitoring data. Survey responses further demonstrate **the different approaches that States are taking to detect contamination.**

Many States have not formalized their approach to all activities related to obtaining or using monitoring data; rather, they rely on case-by-case evaluations and their best professional judgments. Others have formalized policies, procedures, or guidelines for these activities, but they are not necessarily alike (i.e., different monitoring components are included by different States, and even when the States include the same individual components, they do so in different ways).

Formal Procedures for Obtaining Groundwater Quality Information

Most States have formalized approaches to *collecting and analyzing* groundwater quality samples. At least 17 States rely on Federal guidelines. A few

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[1] Engerg, 1983, also notes inadequate data collection for pesticides, radionuclides, and microbial activity in groundwater in Nebraska. Similar inadequacies are being found in the seven other States where USGS is conducting appraisals of groundwater quality data (Ragone, 1983).

States prepare their own protocol manuals (e.g., seven States for collecting samples and eight States for analyzing samples).

To determine which *parameters to measure at a particular site*, many States also rely on Federal guidance through lists prepared for various regulatory programs and laws (e.g., the National Interim Primary Drinking Water Regulations, coal mining regulations, and the list of Priority Pollutants). Reliance on Federal lists is a problem for one State, which commented that routine sampling as required in the Safe Drinking Water Act needed to be changed to cover substances more commonly used in the State.

Formal Procedures for Using Monitoring Data

Forty-three States make *routine comparisons of monitoring* data with quality standards. Of the 23 States that described their efforts, 13 make routine comparisons only for drinking water; 6 conduct routine comparisons in relation to specific facilities or permit programs for activities with the potential to contaminate groundwater; 2 make routine comparisons for all monitoring wells; and 2 make comparisons only during special studies (e.g., contamination investigations or public health studies).

Twenty-two States have formal policies on the *confidentiality of the groundwater information* that they collect. State policies on public accessibility to groundwater information vary. For example, in some States information is confidential only if litigation or a trade secret is involved. Information may be confidential in some States if requested by landowners. In one State, information is confidential only if pollution is confined to the property of the polluter. One State noted that essentially nothing is confidential.

All but one State detect groundwater contamination by *responding to complaints* of suspected contamination. About one-half of the States have formal policies, guidelines, or procedures for this purpose. Types of formal policies vary, ranging from record-keeping activities to policies that are incorporated in regulatory programs for particular sources. Four States have established, or are in the process of developing, special groundwater contamination response programs.

A few States noted problems in responding to complaints about possible contamination. The problems primarily reflect limited resources for the effort. In one State only a fraction of the complaint responses were timely. Another State noted that it sometimes charges for sample analyses.

USE, PREFERENCES, AND PROBLEMS WITH TECHNIQUES FOR HYDROGEOLOGIC INVESTIGATIONS

Use and Preferences for Techniques

The use and preferences of the States for various techniques to collect hydrogeologic data are shown in table 32. Most States use a variety of techniques to conduct hydrogeologic analyses. Although some States use a technique routinely, others may use it only in special circumstances or not at all. Certain techniques are notable for their routine use by most States (e.g., unpublished and published studies, mapping, and excavations and drilling). Other techniques stand out because they are *not* used routinely by many States (e.g., remote sensing with satellites, hydraulic testing tracer tests, contaminant transport modeling, and ground-penetrating radar), but some States apply these techniques in special circumstances.

Only excavations and drilling test wells are *preferred* by more than one-half the States. Reasons given for preferring particular techniques include: cost, time, availability of equipment, and technical capability (relates to ease of use, staff expertise required, reliability and accuracy, value of results,

Table 32.—OTA State Survey Responses: State Use and Preferences for Techniques for Hydrogeologic Investigations

	Number of States:		
Categories of techniques[a]	Using routinely	Using in special circumstances	Having preference for use
Unpublished and published information: (Existing studies)	44	3	24
Mapping	42	7	20
Remote sensing:			
Aerial photography	21	28	9
Satellite imagery	2	26	0
Excavations and drilling:			
(Test wells)	40	9	32
(Stratigraphy)	39	8	13
Geologic sampling	NQ[b]	NQ	NQ
Hydrometeorologic measurements: (Climate)	28	16	0
Surface hydrology:			
Hydraulic measurements (watershed analysis)	28	19	0
Surface water sampling	NQ	NQ	NQ
Subsurface hydrology:			
Potential measurements	NQ	NQ	NQ
Hydraulic testing:			
(Tracer tests)	3	34	4
(Aquifer tests)	25	25	19
Laboratory testing	NQ	NQ	NQ
Water quality sampling	NQ	NQ	NQ
Hydrogeologic systems analysis:			
Modeling			
(Groundwater flow modeling)	11	34	5
(Contaminant transport modeling)	3	35	3
Geostatistics	NQ	NQ	NQ
Surface geophysics:			
Electrical resistivity and electromagnetic conductivity (Surface potential)	10	32	7
Ground-penetrating radar (Surface-penetrating radar)	3	24	1
Shallow geothermic method (Temperature)	7	18	0
Subsurface (borehole) geophysics[c]	21	24	13
Hydrogeochemistry—(sniffers)[d]	7	23	1

[a] The techniques listed are the same as those presented in ch. 5. The terminology used in the OTA State survey is shown in parentheses, if different.

[b] The OTA State survey did not specifically question States about their use and preference for this technique.

[c] The States were questioned about subsurface geophysics in general. Information on specific techniques was not requested.

[d] Sniffers were the only hydrogeochemistry technique included in the survey. More conventional measurements (e.g., pH) are probably used by more States with greater frequency.

SOURCE: Office of Technology Assessment.

Photo credit: National Water Well Association

Although many techniques are available for conducting hydrogeologic investigations, some techniques are not used routinely such as ground-penetrating radar.

Table 33.—OTA State Survey Responses: State Problems With Implementing Hydrogeologic Analyses

Number of States[a]	Types of problems
Technical problems:	
13	Intensive data requirements for particular techniques and lack of data
16	Difficulties in interpreting data and with accuracy of techniques (e.g., for dealing with multiple sources and/or complex hydrogeologic environments)
4	Lengthy time required to conduct analyses
1	Timing constraints (e.g., seasonal limitations with some equipment)
2	High expense and questionable cost effectiveness
4	Limited technology (e.g., most organic contaminant analyses require collection of water quality samples; monitoring techniques are inadequate for karst environments; and contaminant transport models are not well developed)
Institutional problems:	
19	Lack of manpower
36	Lack of funds
27	Inadequate technical expertise (e.g., difficulty attracting and/or retaining qualified professionals)
13	Unavailability of equipment
2	Over-reliance on consultants
1	Inadequate laboratory capabilities
2	Difficulties in keeping up with technical advancements
2	Lack of interagency coordination
1	Lack of public confidence in the State
Legal problems:	
2	Water rights conflicts
10	Difficulties in obtaining site access (e.g., permission to drill offsite)
1	Confidentiality of information (e.g., proprietary pumpage records)
1	Difficulties in recovering costs of investigations from polluters

[a] Forty-nine States responded to this question.

SOURCE: Office of Technology Assessment.

and applicability to hydrogeologic conditions). These factors influence both the choice of techniques for hydrogeologic investigations that a State conducts and the decision on what the State can reasonably require under its regulatory authority.

Problems With Hydrogeologic Investigations

Forty-nine States described problems in conducting hydrogeologic analyses. Table 33 classifies these problems with analyses as technical, institutional, or legal. General findings from this table are below:

- The States experience a variety of problems in conducting hydrogeologic analyses, and different States have different problems.
- The most common problems are institutional. Funding for analyses is a problem for the highest number of States. Other frequently cited institutional problems, often related to funding, include inadequate technical expertise, lack of manpower, and unavailability of equipment.
- The most common technical problems include: difficulties in interpretation of data, inaccuracy of techniques, and intensive data requirements for particular techniques. Four States noted a lack of technology to investigate particular contaminants or hydrogeologic environments, and seven others noted a need for advancements in detection techniques.
- Legal problems with the use of hydrogeologic techniques were reported by relatively few States. The most common is obtaining access to areas to drill and investigate possible contamination.

CHAPTER 7 REFERENCES

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Correction

Chapter 8

The Correction of Groundwater Contamination: Technologies and Other Alternatives

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Chapter 8

The Correction of Groundwater Contamination: Technologies and Other Alternatives

CHAPTER OVERVIEW

Correction is broadly defined in this study to include reducing concentrations of, eliminating, or otherwise controlling contaminants in groundwater. This chapter describes the principal technical and management options available for corrective action and analyzes them in terms of their applicability under different conditions, performance, and stage of development. Technical options are categorized under containment, withdrawal, treatment, and in-situ rehabilitation; management options, which may have technical components, are a fifth category. These categories generally reflect differences among alternatives in terms of how and where substances are acted upon.

Although there is a wide variety of alternatives for correcting groundwater contamination, their effectiveness is uncertain. Experience with them is limited, their applicability can be determined only in relation to given site conditions, and their performance over the long term is an unknown. Some technologies are new, but many are commercially available, having been developed for surface water, industrial, and other purposes.

SELECTING A CORRECTIVE ACTION STRATEGY

The principal options available for corrective action are shown in table 34. Although there is a wide variety of options, no one alternative is capable of responding to all conditions likely to be found at a groundwater contamination site. Rather, options tend to address specific hydrogeologic components, objectives, or steps (refer to table 24) in a corrective action process. For example, options in the treatment category assume that contaminated water is already in the treatment system and do not address how it will be removed from the subsurface (e.g., with withdrawal methods). Thus, in practice, alternatives are combined in a *corrective action strategy* to take advantage of their complementarities.

Selecting a combination of alternatives involves making tradeoffs—among time, costs, performance, and other factors—and not all tradeoffs are quantifiable. As yet, there is no standard approach to formulating corrective action strategies, in large part because groundwater contamination is site-specific and experience is limited. Experts contacted for this study stressed the need for a more scientific and less ad hoc approach in applying and tailoring combinations of techniques to sites. Such a methodology would systematically consider site conditions, resource constraints, and performance objectives in evaluating and selecting among alternatives.

Experience appears to show that the **selection of a corrective action strategy is not primarily based on lowest costs. Rather, selection appears to be based on how quickly methods can be implemented, how quickly they are expected to achieve desired results, and the uncertainty associated with their performance.** Considerations in selecting techniques, which have been identified on the basis of case histories, include: the potential for a public

Table 34.—Corrective Action Alternatives: Techniques and Descriptions[a]

I. **Containment**: This category consists of geotechnical methods that act to limit the mobility and prevent the further spreading of contaminants. Contaminants are not actually removed from the subsurface but are contained or isolated from the rest of the environment—e.g., via physical barriers or hydrodynamic pressures. Techniques are applied in relation to either the contaminants or their source.

1. *Slurry Wall*: Consists of a material (slurry) barrier wall constructed in-place; is usually located below the water table and surrounding a site to limit the horizontal migration of contaminants in the saturated zone; is also used to reduce hydraulic gradients, facilitate withdrawal, or channelize groundwater flow.
2. *Sheet pile*: Consists of a material (e.g., concrete, steel, or wood) barrier wall inserted into place by driving or vibration; is usually located below the water table and around a site to limit the horizontal migration of contaminants in the saturated zone.
3. *Grouting*[b]: Consists of a material cutoff injected into voids of water-bearing strata either to cover, bottom seal, or bind together the subsurface materials at a site.
4. *Geomembrane cutoff*: Involves the insertion of synthetic sheeting into an open trench (combining aspects of both the slurry wall and sheet pile) to form a barrier wall; is used primarily to limit the horizontal migration of contaminants in the saturated zone.
5. *Clay (or other) cutoff*[c]: Clay (or other material, e.g., concrete) barrier wall; normally is constructed above the water table and downgradient of a site to limit the horizontal migration of contaminants in the unsaturated zone (which is commonly negligible).
6. *Liner*[d]: Consists of a material (e.g., clay or synthetic) barrier constructed or emplaced to isolate (e.g., cover or seal) contaminating sources in order to limit the vertical migration of contaminants; is often a facility design component.
7. *Natural containment*: Involves limitation of contaminant mobility by naturally occurring geochemical, geologic, and/or hydrologic conditions; is evaluated by analytical and/or empirical methods.
8. *Surface sealing*[d]: Is used as an infiltration control measure to limit the vertical migration of contaminants either by reducing leachate production and/or recharge.
9. *Diversion ditch*[d]: Is used as an infiltration control measure to limit surface runoff into a contamination management area (e.g., a slurry-walled area) by channelizing and diverting surface drainage.
10. *Hydrodynamic control*: Limits the horizontal migration of contaminants in the saturated zone through selective pumping and the subsequent creation of pressure troughs or pressure ridges.

II. **Withdrawal**: Withdrawal options include methods for either directly removing or facilitating the removal of contaminated groundwater and/or contaminated soils from the subsurface. Techniques are principally applied in direct relation to the contaminants.

1. *Pumping*: Involves the removal of contaminated groundwater by pumping from wells or drains; controls the lateral (and in some cases, vertical) migration of contaminants; can be used for flushing (via artificial recharge).
2. *Gravity drainage*: Involves the removal of groundwater from the subsurface using the force of gravity (e.g., using sumps of French drains) instead of pumps; controls the lateral (and in some cases, vertical migration of contaminants.
3. *Withdrawal enhancement*: Enhances the ability to withdraw either groundwater or contaminants, typically by increasing contaminant solubility in water (e.g., by injecting steam or heat, bacteria or nutrients, or surfactants).
4. *Gas venting*: Removes gases associated with contamination (e.g., methane and petroleum-related products).
5. *Excavation*: Involves the direct removal of contaminated soil and/or groundwater resulting from source leakage.

III. **Treatment**: This category includes physical and chemical/biological treatment methods for detoxifying contaminants found in groundwater. These methods presume that contaminants have already been withdrawn from the subsurface (e.g., via withdrawal methods) in the form of contaminated groundwater or contaminated soils. Treatment can be applied at the source, at the site of contamination (e.g., in on-site treatment units), prior to the distribution of groundwater for use (e.g., in municipal wastewater treatment facilities), and at the point of end use (e.g., at the tap).

a. Physical treatment

1. *Skimming*: Involves the removal of floating contaminants (e.g., oil, grease, and hydrocarbons) in a multi-layer solution.
2. *Filtration*: Involves the physical retention and subsequent removal of contaminants present as suspended solids.
3. *Ultrafiltration*: Involves the physical filtration, through semi-permeable membranes, of suspended and dissolved metals, emulsified hydrocarbons, and substances of high molecular weight.
4. *Reverse osmosis*: Involves the osmotic filtration, through semi-permeable membranes, of contaminants (e.g., metals and radioactive wastes) present as dissolved solids; operates at high pressures (up to 1,500 psig).
5. *Air stripping*: Uses air injection to facilitate the volatilization and removal to the atmosphere of contaminants (e.g., volatile organics and hydrogen sulfide) that are present in water as dissolved solids.
6. *Steam stripping*: Involves the fractional distillation of volatile organics or gases by heating.

b. Chemical/biological treatment

7. *Precipitation/clarification/coagulation*: Removes contaminants (e.g., suspended and colloidal solids, phosphates, and heavy metals) through the use of chemical additives such as coagulants and coagulant aids.
8. *Ion exchange*: Removes selected ions (primarily inorganic) via the exchange of ions between an insoluble solid salt ("ion exchanger") and a solution containing the ion(s) to be removed.
9. *Adsorption*: Removes contaminants (primarily organics) via their tendency to condense, concentrate,

Table 34.—Corrective Action Alternatives: Techniques and Descriptions[a]—continued

or adhere on the surface of another substance (e.g., granular activated carbon and synthetic resins) with which they come into contact.

10. *Electrodialysis*: Separates and removes positive or negative ions under the action of an electrical field.
11. *Chemical transformation*: Involves oxidation-reduction reactions for the chemical conversion of contaminants to less toxic substances (e.g., by ozone treatment, hydrogen peroxide treatment, ultraviolet photolysis, and chlorination).
12. *Biological transformation*: Involves the transformation and removal by micro-organisms of dissolved and colloidal biodegradable contaminants; includes both aerobic and anaerobic processes.
13. *Incineration*: Involves the high-temperature transformation of contaminants into constituent components; many types of thermal destruction systems are included.

IV. ***In-situ rehabilitation***: In-situ rehabilitation techniques are directed at immobilizing or otherwise detoxifying contaminants in place.

1. *Biological degradation*: Involves either stimulating the growth of native microflora or injecting specific organisms to consume or otherwise alter contaminants.
2. *Chemical degradation*: Involves the injection of specific chemicals that react with or otherwise alter contaminants.
3. *Water table adjustment*: Involves either the isolation of the contaminated zone (and creation of a detoxifying unsaturated environment) by lowering the water table or the artificial inducement of increased flushing action by raising the water table.
4. *Rehabilitation via natural processes*: Involves the natural degradation, dispersion, or detoxification of contaminated groundwater; is evaluated by analytical and/or empirical methods.

V. ***Management options***: Management options are usually applied either to prevent further contamination or to protect potential exposure points from contaminated groundwater. These methods thus focus on sources and exposure points rather than on the contaminants per se. The methods also tend to be institutionally-based rather than technology-based.

1. *Limit/terminate aquifer use*: Limits access or exposure of receptors to contaminated groundwater.
2. *Develop alternative water supply*: Involves the substitution of contaminated groundwater with alternative supplies (e.g., surface water diversions and/or storage, desalination, and new wells).
3. *Purchase alternative water supply*: Includes bottled water and water imports.
4. Source removal[e]: Involves the physical removal of the source of contamination and includes measures to eliminate, remove, or otherwise terminate source activities; could also include modification of a source's features (e.g., operations, location, or product) to reduce, eliminate, or otherwise prevent contamination.
5. *Monitoring*: Involves an active evaluation program with a "wait and see" orientation.
6. *Health advisories*: Involves the issuance of notifications about groundwater contamination to potential receptors.
7. *Accept increased risk*: Involves the decision to accept increased risk; is usually a "no action" alternative.

[a] Based on Woodward-Clyde Consultants, Inc., 1983. See this reference for a detailed bibliography on specific corrective action alternatives.
[b] Can be considered a form of chemical immobilization if injected directly into the plume of contamination.
[c] Physical barriers located above the water table will not affect the horizontal migration of contaminants in the saturated zone.
[d] Most often used in the context of either "source removal" or the prevention of recharge to the groundwater system, rather than as a containment option per se.
[e] Modification of a source's features is often an important element of corrective action in the context of preventing future groundwater contamination (i.e., reducing the need for future corrective action).

SOURCE: Office of Technology Assessment.

health or environmental hazard, the potential for any hazard to become more serious over time, the potential for loss of public confidence, the potential for liability, and fear of the unknown (Woodward-Clyde Consultants, 1983).

Technical and Non-Technical Conditions Determining the Applicability of Corrective Action Alternatives

The applicability and selection of alternatives for a groundwater contamination problem depend on site conditions. Conditions are technical (e.g., geologic setting, aquifer type, saturation, and type and concentration of substances) and non-technical (e.g., cost, time, safety, and institutional factors). They are described in detail in appendixes F.1 and F.2, respectively.

There are site conditions that limit all *technology-based* corrective action strategies, assuming a stringent criterion for contaminant reduction, elimination, or control. Among these conditions are: 1) the presence of multiple bodies of contamination at a site and/or complex mixtures of substances; 2) heterogeneous, highly complex aquifers; 3) depths of contamination beyond approximately 20 meters; and 4) the presence of substances that partition (i.e., separate) out of water and are non-biodegradable. The degree to which these constraints effectively preclude application of technology depends to a large extent on whether substances can be withdrawn and treated.

Often withdrawal and treatment are not possible. For example, the application of some withdrawal methods (e.g., pumping) is limited in unconsolidated, fine-grained materials of low permeability and may be impractical (in terms of time and costs) if high water volume handling requirements are involved. Individual treatment techniques address specific types of substances, and no single technique is applicable to the mix of substances often found in groundwater. Further, sudden temporal changes in the types and/or concentrations of substances passing through a treatment system can lessen treatment effectiveness. Thus, several treatment techniques would generally be required to treat contaminated groundwater, but even then there is no guarantee that all substances will be reduced to desired levels.

Other conditions that determine and often restrict the applicability of corrective actions to a given site include:

- *hydrogeology*, e.g., methods requiring construction (many containment methods and excavation) are often technically impractical in hard rock; material barriers depend on the presence of a horizontal stratum of low permeability and sufficient thickness for anchoring; and highly fractured sedimentary or crystalline rock precludes the use of most techniques except pumping, treatment (if withdrawal can be accomplished), and grouting;
- *types and concentrations of contaminants*, e.g., special handling and disposal may be required with options involving construction or withdrawal in the presence of certain substances; high concentrations severely reduce the efficiency of withdrawal; mixtures of substances reduce the efficiency of treatment; and multiphase flow (as when substances are immiscible in and denser than water) poses special design and implementation problems for most methods;
- *depth*, e.g., methods involving construction equipment are generally limited to depths of approximately 20 meters;
- *environmental and health effects*, e.g., health effects are associated with containment and management options that allow the continued presence and potential for continued migration of substances; environmental effects potentially include alterations to existing groundwater flow patterns if construction or pumping is involved and the introduction of biological or chemical agents—and the continued presence of *altered* substances—with in-situ rehabilitation; and some treatment options can have air pollution side-effects (air stripping);
- *cost*, e.g., depending on site conditions, costs can be tens of millions of dollars or more; containment tends to be capital-intensive during construction and installation with relatively small long-term operation and maintenance costs, while withdrawal is less capital-intensive overall but has significant long-term operation and maintenance costs; and cost considerations have effectively precluded corrective action in areas larger than about 0.1 km^2 and for volumes exceeding about 1,000 m^3; and
- *performance objectives* in terms of the continued presence of substances—e.g., excavation eliminates substances from a site relatively quickly but depends on the availability of an alternative site for disposal of excavated materials; pumping may remove high concentrations of substances in the near term, but decades of pumping may be required before a significant additional reduction is achieved; and treatment may also be required over the long term and removal efficiencies are highly variable.

Appendix F.3 summarizes information about conditions determining the applicability of corrective action alternatives in relation to the OTA source categories discussed in chapter 2 (refer to table 5). **Essentially, no technically based corrective action can stop a source from causing contamination: 1) if the source is deep,** such as many sources in Category I (i.e., sources designed to discharge substances) and Category V (i.e., sources that provide a conduit); **or 2) the source releases substances over a wide area or if large volumes of water are involved,** as in Category IV (i.e., sources that discharge substances as a consequence of other

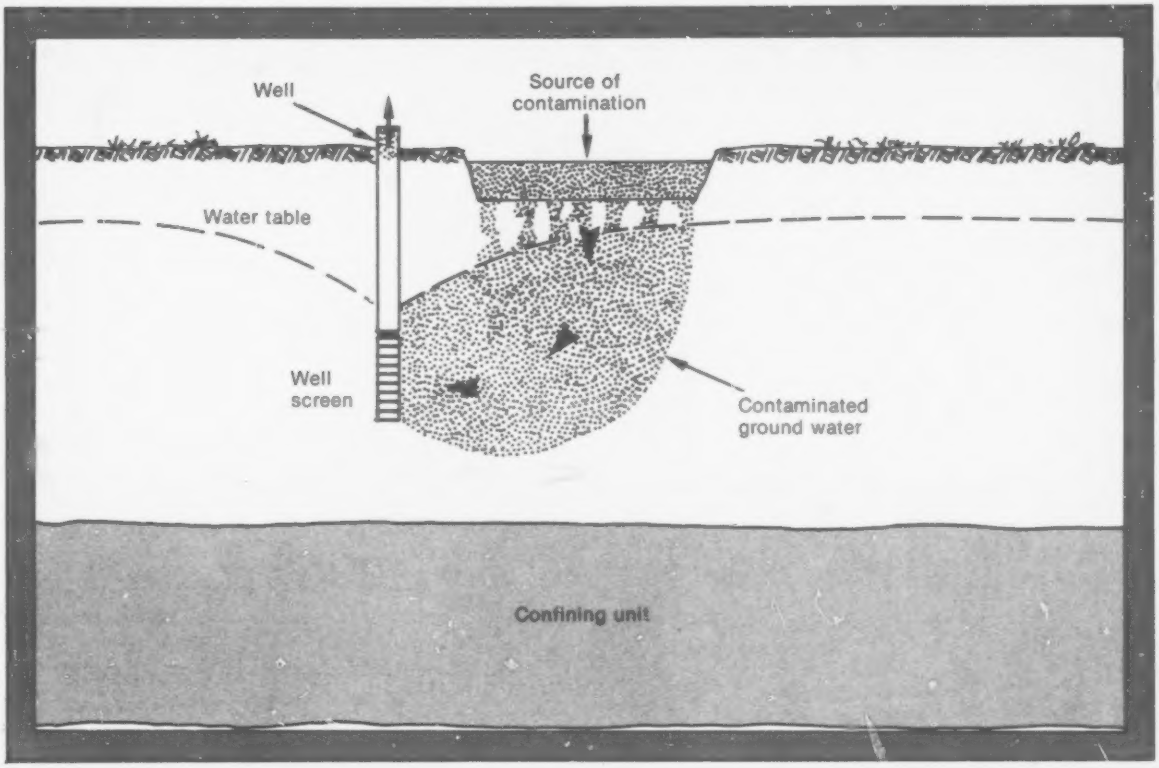
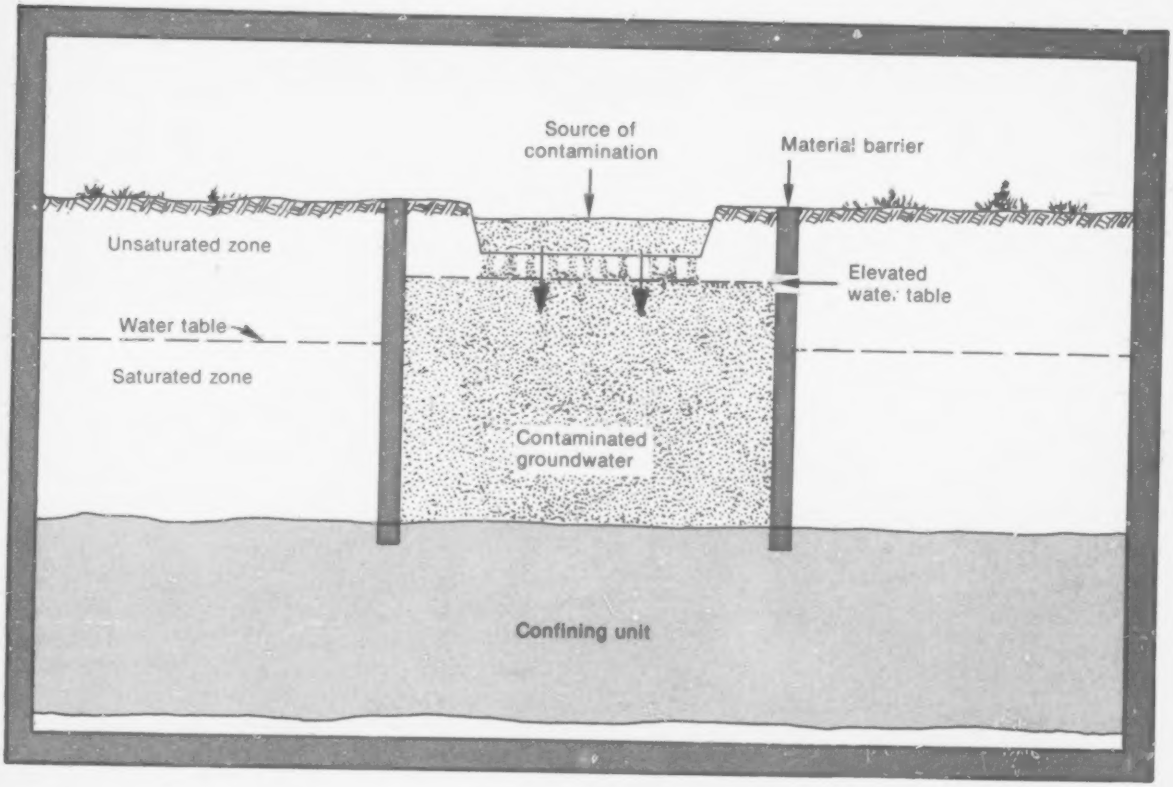

Well
Source of contamination
Water table
Well screen
Contaminated ground water
Confining unit

Photo credit: Geraghty & Miller, 1983

Movement of contaminated groundwater can sometimes be controlled by pumping (i.e., hydrodynamic control) as shown above. Groundwater that is withdrawn must subsequently be treated and/or disposed of in some way; below, discharge lines carry recovered water away from the site.

Photo credit: Office of Technology Assessment


Source of contamination
Material barrier
Unsaturated zone
Elevated water table
Water table
Saturated zone
Contaminated groundwater
Confining unit

Credit: Geraghty & Miller, 1983

Containment options that use material barriers depend on the presence of a horizontal stratum of low permeability and sufficient thickness for anchoring as shown above; some type of pumping scheme (e.g., wells or drains) may also be needed to prevent the overflow of contaminated water from inside the barrier. Backfill is being pushed into an almost completed slurry wall in the photograph below.

Photo credit: National Water Well Association

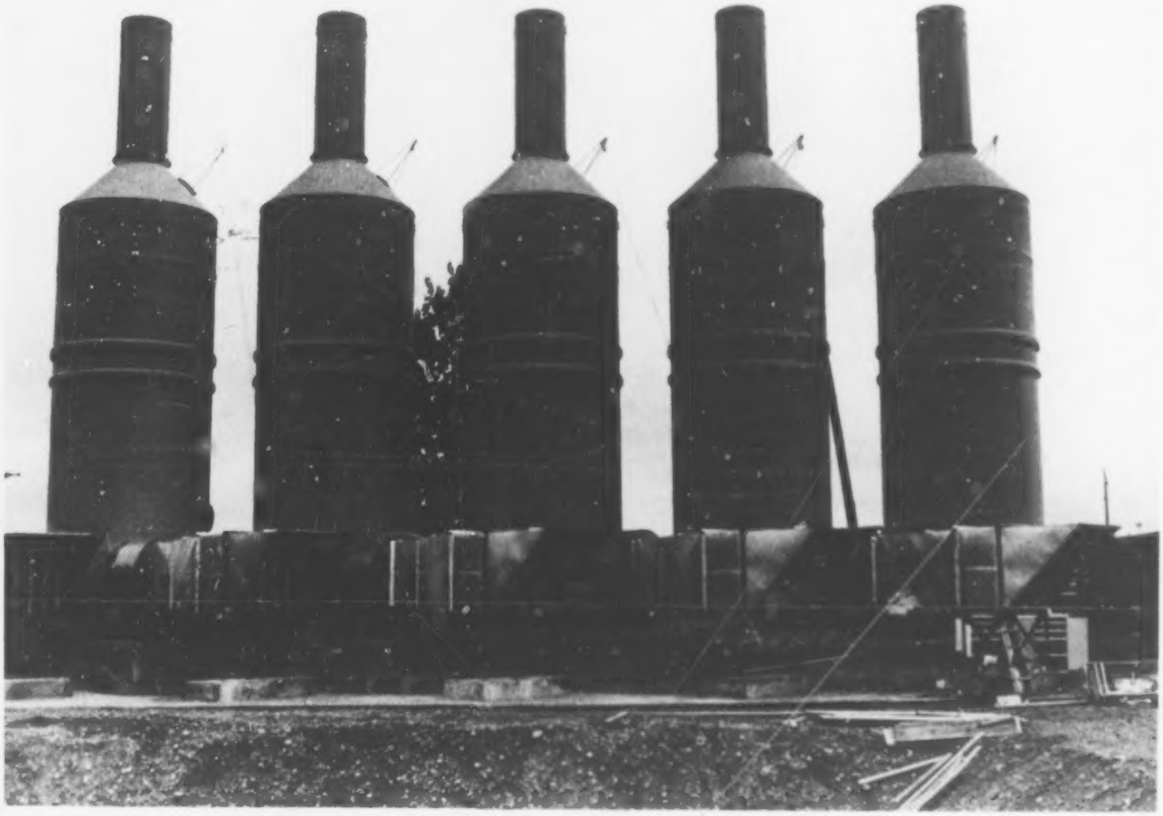


Photo credit: U.S. Environmental Protection Agency

Airstripping towers can be used to remove contaminants from groundwater; however, precautions must be taken to minimize any associated air pollution problems.

activities including pesticide and fertilizer applications).

Performance of Corrective Action Alternatives

Corrective actions have been taken to improve groundwater quality, but how well they perform remains uncertain over both the short and the long term. Inability to characterize performance of corrective measures arises because of the following five interrelated factors.

1) **Performance is relative.** Evaluation of performance requires the establishment of a benchmark or a target level for comparison. For example, when the desired reduction in contaminant concentrations is minor, many corrective action alternatives may qualify as "effective," but as the levels of desired or required cleanup increase, many alternatives may no longer qualify. Performance is also measured not only against existing conditions but in relation to future conditions—i.e., the suitability of improved quality to satisfy likely future uses.

2) Performance must be assessed in relation to the specific conditions at a given site (see the preceding section of this chapter). **The site-specificity of groundwater contamination problems and, in turn, of the applicability of corrective action alternatives precludes a meaningful generalized assessment of technology performance.**

3) Even when site information is available, there **is always some degree of uncertainty about the subsurface environment**—e.g., which substances are present, at what levels, and where (see ch. 5)—**that can limit the effectiveness of alternatives in unforeseen ways.** The principal uncertainty factors that influence performance are summarized in table 35 and relate to materials compatibility, the heterogeneity of the aquifer, and the types of substances present. Others are related to the qualifications of personnel and the quality of construction, handling, and operation.

4) There is **virtually no long-term experience upon which to base the assessment of corrective actions.** For example, although there have been federally funded cleanup activities under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other Federal statutes, none has involved groundwater (see ch. 9). As a consequence, a thorough performance evaluation of individual alternatives under different site conditions will not be available in the near term. Although many case histories are reported in the literature, they often do not contain enough detail for an evaluation of technology performance. In addition, access to information appears limited because it is often proprietary or involved in litigation.

5) The **projected performance of technology and the degree of uncertainty about its performance depend on the time available to meet cleanup objectives or standards desired** (e.g., as specified in permits, presented in a notice of regulatory compliance, and in response to public pressures) **and on available funds.** For example, in addition to specifying the levels to which the concentrations of substances must be reduced, a time frame may also be specified.[1] Time constraints may preclude many corrective action alternatives from consideration, perhaps resulting in a choice among more costly options; or desired cleanup standards may be neither technically nor economically feasible in the time specified.[2]

Although an accurate performance assessment is not presently possible, **it is possible to reduce the uncertainties associated with performance and/or to improve the likelihood that an alternative will perform well.** Examples are described below:

- The evaluation, selection, design, and implementation of corrective action alternatives are based on information obtained from hydrogeologic investigations. Thus, improving the reliability of hydrogeologic information (see ch. 5) will improve corrective action decisionmaking.
- Realistic expectations in terms of objectives, time, and costs are important in ensuring that failure is not inevitable.
- Monitoring can gauge long-term effectiveness and enable modification of the corrective actions chosen if necessary. But measuring performance is indirect and varies among the alternatives. Possible indicators of performance are presented in table 35.
- Quality control and quality assurance procedures—e.g., regarding the use of construction equipment on-site and the handling and placement of physical barriers—can also minimize the likelihood of poor performance.

Importantly, different types of uncertainties are associated with different alternatives, and the performance of some may be more certain (though *not* necessarily more desirable) than others, depending on site conditions. Management options are most often selected because their performance is the most certain. For example, terminating aquifer use depends neither on subsurface hydrogeology nor on the nature and behavior of substances; over the long term, however, there may be a risk of public exposure to substances remaining in the subsurface.

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[1] In a survey of remedial action projects undertaken for EPA (SCS Engineers, 1981), legal action to identify "responsible" parties for corrective action alone varied from 4 to 9 years.

[2] For example, if cleanup standards must be achieved in, say, 5 years, then a time- and capital-intensive method of containment may have to be chosen (e.g., a slurry wall requiring replacement once every 50 years), precluding methods that have long-term operational requirements but smaller capital costs (e.g., hydrodynamic control). A net present value criterion would select hydrodynamic control in the absence of a near-term time constraint. However, a pumping system may achieve a 90-percent reduction in contaminant concentration levels in 5 years, but an additional 50 years may be required to reach a goal of 95-percent reduction.

Table 35.—Corrective Action Techniques: Objectives, Performance, and Status

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
Containment					
1. Slurry wall	To halt the horizontal migration of contaminants from a contamination plume; often used in conjunction with surface seal, run-on, and runoff controls.	• Long-term materials compatibility, particularly with certain organic solvents such as aromatics and halogenated species. • Wall consistency and integration with the confining bed. • Longevity of wall integrity. • Quality of design and installation.	Performance of a slurry wall is is determined by various methods. Monitoring well data outside of the wall can indicate the degree of leakage. Hydraulic head differences determine leakage potential; actual leakage can be calculated. Head measurements in underlying aquifers determine potential for vertical leakage. Permeability measurements of confining bed also determine leakage potential.	2	Technology for conventional, trenched slurry walls is well established as a construction dewatering practice; however, allowable leakage for construction applications is less critical than for contamination applications. In general, long-term (30 years) performance evaluations are not available because the operation requirements of dewatering are usually short term (less than 1 year). Historical records of long-term performance under exposure to varying contaminant types is also unavailable. Advanced techniques, such as the vibrating beam emplacement method, have a limited history of application to contamination problems and should be considered unproven.
2. Sheet pile	Same as slurry wall.	• Occurrence of premature pile failure, especially in the presence of highly concentrated corrosive contaminants.	Same as slurry wall except that measurements are taken at specific places where leakage is expected to occur, e.g., at pile joints and where piles are integrated with the confining bed.	2	This technique is conventionally used for construction dewatering. Its long-term viability in corrosive environments (e.g., acid wastes) is unproven. Also, the effectiveness with which the method can limit contaminant migration is questionable for stringent performance criteria (e.g., if low or no leakage is desired.)
3. Grouting	To encapsulate contaminants (via bottom and lateral grouting).	• Contact between the grout materials and all fracture and pore spaces. • Compatibility of formation fluids and wastes with grout materials.	Encapsulation processes cannot be easily monitored or controlled (e.g., a barrier wall can be more easily inspected during construction than injected grout; and grout injection is not as easily controlled as trenching). Interpretation of monitoring well data for downgradient contaminants is the principal measure of performance.	2	Grouting is conventionally used in mine dewatering and dam construction. Design requirements in historical uses are generally to *limit* water flow, not to minimize or eliminate flow or to encapsulate contaminants.

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Table 35.—Corrective Action Techniques: Objectives, Performance, and Status—continued

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
4. Geomembrane	Same as slurry wall.	• Compatibility of synthetic membranes with organic solvents. • Installation of a vertical liner with grout backfill without damage. • Integration of the liner with the confining bed.	Same as slurry wall.	3	Contamination applications are are in the R&D phase although the technology is commercially available. Field tests are only now being conducted; long-term performance data are not available.
5. Clay cutoff	To halt the horizontal migration of contaminants (in the unsaturated zone).	• Compatibility of materials and quality of installation.	Monitoring in the vicinity of the cutoff can be accomplished with suction lysimeters, core samples, and other techniques applicable to the unsaturated zone.	2	A clay cutoff is a standard construction technique but it has limited utility in groundwater contamination applications because horizontal migration in the unsaturated zone is most often negligible.
6. Liner	To limit the vertical migration of contaminants; commonly used as a facility design component.	• Occurrence of punctures due either to improper installation or to settling of underlying materials. • Impacts of organic solvents on synthetic liners or clays—e.g., holes or reduced effective permeability. • Quality of materials selection and installation.	Performance of liners can be monitored by underdrain collection systems or conventional monitoring well techniques.	1	Liner technology is well established and has been applied extensively to groundwater contamination problems. However, long-term performance data for both synthetic liners and compacted clays are limited. The use of underliners is limited mainly to hazardous-waste facility design.
7. Natural containment	To contain or otherwise limit the migration of contaminants via retardation in aqueous media, in geologic formations, or by hydrogeologic conditions.	• Representativeness of characterization of hydrogeology and contaminant retardation. • Accuracy and completeness of data, especially concerning contaminant retardation. • Heterogeneity of subsurface conditions.	Detection of contaminants in monitoring wells can verify predicted migration rates.	5,6	Techniques are available to predict the general direction and rate of movement of natural flow systems. But techniques used to predict contaminant migration rates and concentration levels (e.g., solute transport models) are not well established and subject to great uncertainty, particularly in the absence of supporting data.
8. Surface sealing	To limit infiltration into the contaminated area; commonly used in conjunction with runoff diversion ditches and material barriers (e.g., slurry wall and grouting) and with	• Quality of management, inspection, and repair.	Visual inspection can locate holes or cracks. Increased leachate production indicates leakage. Also, increased pumpage requirements in head management system may indicate leakage	1	Conventional construction techniques are used to emplace surface seals. Effective infiltration control requires constant maintenance (e.g., due to the formation of stress cracks from settling or drying after dewatering).

Table 35.—Corrective Action Techniques: Objectives, Performance, and Status—continued

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
	source isolation (e.g., to eliminate leachate production).				
9. Diversion ditches	To divert surface runoff away from the contaminated area.	• No major concerns.	Visual inspection is used to measure performance—e.g., during precipitation events.	1	This technique is a conventional construction method used for run-on/runoff control. It is often used in conjunction with surface seals.
10. Hydrodynamic control	To isolate contaminants via countering hydraulic gradients.	• Changes in local flow patterns due to modifications in existing pumping schemes or to installation of new pumping wells. • Downward flow which could allow contaminant migration into uncontrolled aquifers.	Water levels can be monitored in surrounding wells to observe gradients.	1,4	Techniques are not considered conventional or "on-the-shelf." Management of plumes and contaminant isolation in complex hydrogeologic settings require extensive engineering and testing. Long-term effectiveness is a function of constant fine-tuning to changes in head gradients. In dynamic flow systems (e.g., in systems modified by other pumping uses), pumping rates or patterns will require modification in real time.
Withdrawal					
1. Pumping	To limit the lateral migration of contaminants while gradually removing them from the aquifer matrix and formation fluids. (Source removal and/or isolation is also required to achieve ultimate reduction in contaminant concentrations.)	• The necessary length of time for operations. • Downward leakage of contaminants due to fracture systems, jointing, and abandoned wells.	Contaminant concentration levels can be measured in produced water to determine removal rates; and effects of pumping can be verified by monitoring water levels in surrounding wells. Underlying aquifers must be monitored to detect downward migration. Concentration levels after pumping is terminated must be monitored to determine increases in concentrations due to desorption. Geochemical interactions between contaminants and the aquifer matrix affect the partitioning of the contaminant between solid and water phases; the potential effectiveness and length of operations are dependent on these interactions.	1	Pumping techniques (e.g., wells) are used conventionally for water supply development and more recently for plume management. Techniques are reliable and performance can be verified. Numerous applications to groundwater contamination are in place, and performance data are available.

Table 35.—Corrective Action Techniques: Objectives, Performance, and Status—continued

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
2. Gravity drainage	Same as pumping.	Same as pumping.	Same as pumping.	1	A type of fluid recovery technology, this method is used extensively in dewatering activities and for groundwater contamination. It is a reliable, simple technique which is applicable in many surficial, unconsolidated formations. Performance data are available.
3. Withdrawal enhancement	To enhance contaminant removal efficiencies via the the injection of chemicals, steam, or other additives.	• Lack of proven effectiveness of technology. • Introduction of additional contaminants to the aquifer (e.g., chemical reagents and their byproducts). • Introduction of volatiles to the atmosphere (e.g., via the use of steaming in surficial applications). • Presence of inorganic substances (i.e., use is limited to organic constituents).	Same as pumping.	2,3,4[b]	This technique is not conventionally applied to groundwater contamination problems. Steam or heat injection, although used in confined formations in oil field applications, have not been extensively tested in surficial contamination problems where concentrations of organics are much lower and objectives for removal are more stringent (50% recovery of oil in place is often considered reasonable). Surfactant injection is still considered an advanced technique in enhanced oil recovery operations, and injectants are often considered hazardous.
4. Gas venting	To remove volatile contaminants from the subsurface.	• Lack of proven effectiveness in complex media.	Measurements can be taken using gas collection probes.	1	Gas venting is conventionally used in landfill design and operation. Vapor extraction in the unsaturated zone appears capable of removing the soluble fraction of volatile compounds from the saturated zone.
5. Excavation	To remove contaminated water and/or soil materials.	• Increased contaminant migration (e.g., via breaking of drums or additional infiltration during precipitation). • Availability of secure disposal areas for excavated contaminants. • Extent of contamination and resulting costs.	Contaminant concentration levels can be measured in surrounding soil and aquifer materials and in surrounding waters to verify total removal. Measurements are most accurate if contaminants are highly concentrated and limited in depth and volume.	2	Direct excavation is a conventional technology. However, associated health and safety measures are continually under development and are likely to increase costs substantially.

Table 35.—Corrective Action Techniques: Objectives, Performance, and Status—continued

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
		• Uncertainty increases if contaminants are neither highly concentrated nor limited in depth or volume.			
Treatment	In general, to transform (thereby removing) contaminants via physical, chemical, or biological means.	• Occurrence of shock loadings. • Nature, mix, and concentration of contaminants; uncertainty increases if contaminants are not highly concentrated. • Equipment design and operation (e.g., membrane maintenance for filtration, ultrafiltration, and electrodialysis; and proper controls for providing reagents for adsorption and chemical transformation). • Subsurface hydrogeology to the extent that contaminated groundwater is to be withdrawn from the aquifer.	In general, influent and effluent can be monitored for contaminants.	1[c]	Treatment techniques are generally "on-the-shelf" and with basic engineering can be adapted to many groundwater contamination incidences. However, management of treatment systems for multiple contaminants and for rapidly changing concentrations may prove to be difficult. Performance data are not available for groundwater contamination applications using ultrafiltration, reverse osmosis, steam stripping, ion exchange, and electrodialysis.
In-situ rehabilitation					
1. Biological degradation	To degrade contaminants via the injection of micro-organisms into the subsurface or by stimulating the growth of in-situ bacteria.	• Contact between the reagents and the entire contamination mass, particularly in heterogeneous aquifers. • Predicting the behavior of micro-organisms. • Tailoring micro-organisms to contaminants. • Performance is highly uncertain.	Contaminant levels can be monitored in soil and water.	4,5	Techniques are in the R&D stage with minimal commercial application. They have a potentially limited application to groundwater due to practical constraints such as the volume of organisms required, reaction kinetics, and the assimilitive capacity of organisms for certain contaminants. In heterogeneous formations, access to the entire contaminant mass may be practically impossible. Techniques are most often applied to petroleum-related spills.
2. Chemical degradation	To degrade or immobilize contaminants via the injection of chemicals into the subsurface.	• Contact between the reagents and the entire contamination mass, particularly in heterogeneous aquifers. • Performance is highly uncertain.	Same as biological degradation.	4,5	Techniques are in the R&D stage with minimal commercial application. They have a potentially limited application to groundwater due to practical constraints including reaction kinetics and reactivity of contami-

Table 35.—Corrective Action Techniques: Objectives, Performance, and Status—continued

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
					nants. In heterogeneous formations, access to the entire contaminant mass may be practically impossible.
3. Water table adjustment	To allow for the aerobic degradation of contaminants by lowering the water table.	• Potential for aerobic degradation is limited to certain organic contaminants. • Prediction of degradation rates or processes.	Contaminant concentrations can be monitored in soil and water. Underlying saturated media can be monitored to determine contaminant levels.	4,5	The methods of pumping and gravity drainage used to alter water table levels are well established. Evaluation of the impacts of such adjustments on contaminant degradation, however, is not well defined or established, and the technique is not conventionally applied in plume management. Source isolation is a possible application. Raising the water table can provide flushing benefits in some cases.
4. Natural process restoration	To allow for the degradation and dispersion of contaminants in the natural flow system.	• Prediction of contaminant migration behavior; heterogeneities in aquifer conditions reduce accuracy of predictions. • The presence of non-degradable contaminants that, although highly retarded, continue to migrate at low velocities.	Downgradient levels of contaminants in soil and water can be measured.	5,6	Methods used to *predict* concentration reductions (e.g., solute transport models) are not highly reliable. Monitoring the actual attenuation of contaminants is a conventional practice and performance can be monitored.
Management options					
1. Limit/terminate aquifer use	To minimize the exposure of possible users to contaminated groundwater.	• The ability to shut down domestic wells due to possible public resistance. • The ability to enforce usage patterns in cases of environmental exposure (e.g., to sport fish or streams).	Exposure levels can be monitored; actual use patterns over time can be determined. Performance is also economic—e.g., it may be cheaper to terminate use and import water or develop alternative supplies than to treat supplies or otherwise correct contamination.	6	Historically this is a common response to aquifer contamination.
2. Develop alternative water supply	To provide a substitute water supply by developing alternative water sources.	• Availability of water supply alternatives, especially in water-short areas which may, in turn, limit the long-term growth of an area.	Performance is mainly economic—e.g., it may be cheaper to terminate use and develop alternative supplies or import water than to treat supplies or otherwise correct contamination.	6	In conjunction with limiting/terminating aquifer use, alternative water supply development is a frequently implemented response.

Table 35.—Corrective Action Techniques: Objectives, Performance, and Status—continued

Technique	Objective	Principal components of uncertainty affecting performance	Measuring performance	Development status	
				Summary[a]	Remarks
3. Purchase alternative water supply	To provide a substitute water supply through importation or other purchases.	• Reliance on imports, especially in water-short areas where the supply may be terminated or depleted. • Potential opposition to interbasin transfers.	Performance is mainly economic—e.g., it may be cheaper to terminate use and develop alternative supplies or import water than to treat supplies or otherwise correct contamination.	6	This is a frequently implemented response although generally considered a short-term solution.
4. Source removal	To remove physically the source of contamination.	• Increased contaminant migration (e.g., via breaking of drums or additional infiltration during precipitation). • Availability of secure disposal options. • Extent of contamination and resulting costs. (See Excavation, above.)	Contaminant concentration levels can be measured in surrounding soils, aquifer materials, and waters to verify total removal.	1	Conventional construction techniques are used for source removal although substantial increases in health and safety precautions are required for groundwater contamination applications. Current activity already involves significant health and safety measures.
5. Monitoring	To delineate and track the migration (and concentrations) of contaminants.	• Undetected plume migration because of improper placement or sampling of wells. • Mistakes are difficult to detect until a problem occurs or backup wells around key exposure points are installed.	Performance can be measured by duplicating samples and analyses. Use of qualified personnel are essential for proper well placement and for the overall groundwater quality investigation.	1,6	Conventional technology is used for monitoring groundwater contamination problems and conducting hydrogeologic investigations. If methods are used properly, reliable plume delineation and migration data can be generated (see also ch. 5).
6. Health advisories	To limit the use of contaminated groundwater by advising users of contamination.	• The ability to enforce usage patterns in cases of environmental exposure (e.g., to sport fish or streams). • The ability to shut down domestic wells due to possible public resistance.	Exposure levels can be monitored; actual use pattern over time can be determined. Performance is also economic—e.g., it may be cheaper to terminate use and develop alternative supplies or import water than to treat supplies or otherwise correct contamination.	6	This option is a conventional practice of State and local health departments.
7. Accept increased risk	No action taken.	• The ability to predict contaminant migration. • Corrective action alternatives can be more expensive as the contaminant spreads out (i.e., a larger plume).	Performance is often measured in economic terms.	6	Historically this option is the response to many contamination incidences. Impacts on population are unclear.

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[a] Key: 1—Technology is proven; performance data are available from applications to groundwater contamination problems.
2—Technology is proven in applications other than groundwater contamination; long-term performance data are unavailable for groundwater contamination.
3—Technology is in R&D stage with respect to groundwater contamination applications, although proven for other applications; performance is generally unknown for groundwater contamination problems.
4—Application of technology has been limited to specific, narrowly defined site conditions.
5—Technology is generally in R&D stage; results are unreliable.
6—Technology has been applied historically—e.g., before the development of regulatory programs and consideration of potential long-term impacts.

[b] Withdrawal enhancement techniques that would be a "5" include surfactant injection.

[c] Treatment technologies that would be "2" are ultrafiltration, reverse osmosis, steam stripping, ion exchange, and electrodialysis.

SOURCE: Office of Technology Assessment.

STAGE OF DEVELOPMENT OF CORRECTIVE ACTION ALTERNATIVES

The development status of alternatives is also summarized in table 35. Generally, alternatives for corrective action are commercially available. However, they have usually been developed for industrial and surface water uses, which do not require the level of reduction, removal, and/or control of substances that is necessary for groundwater contamination problems. For example:

- containment methods were developed in the construction industry for dewatering, foundation, and embankment applications;
- withdrawal methods were developed for groundwater supply (i.e., quantity) development and for petroleum recovery;
- treatment methods were developed for wastewater (i.e., surface water) and desalination applications; and
- management options have generally been applied in the areas of wastewater (i.e., surface water) treatment and water supply (i.e., quantity) development.

Some commercial alternatives require only minor modifications, if any, for groundwater contamination purposes. These alternatives include some management options (e.g., the development of alternative supplies) and, to a lesser extent, excavation if precautions are taken with respect to materials handling and disposal.

Other commercial alternatives require continued research and development before they can be applied effectively to contaminated groundwater. For example, containment needs relate principally to the permanence of installation—e.g., materials compatibility, field validation procedures, quality control, and leak detection (EPA, et al., 1983). With respect to treatment, research and development is needed for radionuclides; viruses; certain organic chemicals, including halogenated compounds; and complex mixtures of substances. Research also needs to continue on modifying existing wastewater treatment facilities to handle a broader spectrum of substances than they typically handle. In general, the technologies for treating substances in groundwater are likely to differ substantially from those developed for contaminated surface water and wastewater because of the marked differences among the types and concentrations of substances present.

Some innovative methods are being developed specifically for application to groundwater contamination problems. For example, research and development for in-situ rehabilitation originated in the context of petroleum spills, and withdrawal enhancement techniques are being developed in the context of hydrodynamic control. Because innovative methods tend to be substance-specific, they are likely to be useful only on a limited scale in the long term.

Although some available technology and likely developments appear promising for specific types of contamination problems, technology alone cannot be expected to correct the full range of problems likely to be encountered. It will take years, or even decades, of testing and monitoring to develop reliable performance data. Even then, the knowledge gained will be site-specific.

CHAPTER 8 REFERENCES

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Chapter 9

Federal Efforts To Correct Groundwater Contamination

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Chapter 9

Federal Efforts To Correct Groundwater Contamination

CHAPTER OVERVIEW

Based on a review of statutory and regulatory requirements, this chapter discusses the corrective action programs of the Federal statutes and programs discussed in chapter 3. Information is presented on the sources of groundwater contamination requiring corrective action and the cleanup standards specified under corrective action programs. An overview of Federal experience with corrective action is also provided. *Specific* corrective actions undertaken by either Federal agencies or the responsible parties in response to regulatory or court-imposed requirements were not reviewed for this study.

The major conclusions of this chapter are:

- few Federal statutes provide for corrective action,
- cleanup standards are generally not specified in regulations, and
- Federal agency experience with such actions is limited.

STATUTORY AND REGULATORY PROVISIONS FOR SOURCES OF CONTAMINATION

Federal Government involvement in corrective action efforts for contamination problems can be characterized in one of three general ways:

1. Federal agencies have developed *regulatory requirements* (e.g., permit conditions) for corrective actions for specific sources of contamination (e.g., under the Resource Conservation and Recovery Act (RCRA)).
2. Federal agencies are mandated by statute to *undertake and finance* corrective actions related to specific sources of contamination (e.g., under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA).
3. Explicit corrective action provisions are absent but responsible parties may be required to undertake corrective actions as a result of actions to enforce compliance with regulatory requirements (e.g., drinking water regulations and endangerment provisions).[1]

Details of corrective action provisions for the OTA source categories discussed in chapter 2 are presented in appendix G; the appendix contains information on the type of corrective action efforts required under each statute (e.g., permit conditions or federally funded cleanup activities) and on specified cleanup standards.

Table 36 summarizes the corrective action provisions of the Federal statutes examined in this

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[1] For example, under the Underground Injection Control Program established by the Safe Drinking Water Act, the Environmental Protection Agency may take enforcement action if there is a violation of drinking water regulations or if the health of persons is otherwise adversely affected. In addition, several statutes also contain provisions that allow the Administrator of EPA to bring lawsuits if actions present or may present an "imminent and substantial endangerment" to human health or the environment (e.g., Section 7003 of RCRA, Section 1431 of SDWA, Sections 504 and 311(e) of CWA, and Section 106 of CERCLA).

Table 36.—Summary of Federal Corrective Action Provisions for Sources of Groundwater Contamination

Statute	Provisions	Cleanup standards specified in regulations
Atomic Energy Act[a]	NRC requires that licenses for low-level radioactive waste sites contain plans for taking corrective measures if migration of radionuclides exceeds specified levels.	None
	Corrective action programs have been established by DOE for inactive and active radioactive disposal and storage facilities. Corrective actions with respect to groundwater contamination have not been undertaken.	None
Clean Water Act[a, b]	Federal funds are available for modification or replacement, but not necessarily cleanup, of projects involving the application of sewage sludge or wastewater under the Innovative and Alternative Technology Program (Section 201) that have not met design performance standards.	None
Coastal Zone Management Act	The statute does not authorize development of regulations for sources. Thus, if any corrective actions were to be required with respect to groundwater (e.g., from salt-water intrusion), such actions would be taken under a State program.	None
Comprehensive Environmental Response, Compensation, and Liability Act[a]	Federally funded corrective actions are authorized for sources that release, or threaten to release, specified hazardous substances, pollutants, or contaminants.[c]	None
Federal Insecticide, Fungicide, and Rodenticide Act	No explicit corrective action requirements are established for pesticide users or manufacturers.	None
Federal Land Policy and Management Act (and associated mining laws)	No explicit corrective action requirements are specified for mining operations on Federal lands.	None
Hazardous Liquid Pipeline Safety Act	Although the statute authorizes development of regulations for certain pipelines for public safety purposes, the regulatory requirements focus on prevention generally and do not provide for corrective actions.	None
Hazardous Materials Transportation Act	Although the statute authorizes development of regulations for transportation for public safety purposes, the regulatory requirements focus on prevention generally and do not provide for corrective actions.	None
Reclamation Act[a]	Corrective actions can be undertaken by the Federal Government as part of water development (including groundwater) projects.	None
Resource Conservation and Recovery Act	Subtitle C regulations require corrective actions for hazardous waste landfills, surface impoundments, waste piles, and land treatment areas. Corrective actions are not required beyond the downgradient facility property boundary.	Background levels of hazardous substances (specified on a case-by-case basis), Maximum Contaminant Levels for 14 contaminants established under the Safe Drinking Water Act (if higher than background), or alternative concentration limits (specified on a case-by-case basis).

Table 36.—Summary of Federal Corrective Action Provisions for Sources of Groundwater Contamination—continued

Statute	Provisions	Cleanup Standards specified in regulations
Safe Drinking Water Act	No explicit corrective action requirements are specified for underground injection wells.	None
Surface Mining Control and Reclamation Act[a]	No explicit corrective action requirements are specified for mining operations on Federal lands.	None
	Federally funded remedial actions are authorized by the Rural Abandoned Mine Program.[d] State grants are also provided for abandoned mine programs; States establish reclamation priorities.	None
Toxic Substances Control Act	While the statute specifically addresses PCB disposal sites, no explicit corrective action requirements are established.	None
Uranium Mill Tailings Radiation Control Act[a]	Federally funded corrective actions are authorized for specified inactive sites. The statute explicitly lists those sites for which corrective actions are required.	None for inactive sites.
	Active sites are subject to the same requirements as surface impoundments under RCRA (except that corrective actions must be implemented within 18 months).	Standards for active sites are the same as RCRA (Subtitle C) except that levels for certain radioactive substances are also established.

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[a] The statute authorizes federally funded remedial action programs.

[b] Federally funded corrective actions for oil spills or leaks are authorized if there is a discharge into *navigable waters* (Section 311). There are no cleanup standards, however, specified in the regulations. This provision is relevant to groundwater to the extent that groundwater and surface water may be interconnected.

[c] A "release" includes any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing. Sources explicitly *excluded* by law include radioactive sites covered by other laws and the normal application of fertilizers. (See Section 101(22) of CERCLA.)

[d] This program is being phased out. Although it provided for groundwater restoration, projects undertaken by the Soil Conservation Service have not directly addressed groundwater.

SOURCE: Office of Technology Assessment.

study.[2] The following observations are made about these provisions:

- **Explicit corrective action provisions (e.g., groundwater protection standards) are not specified for all sources of contamination.** No explicit corrective action requirements for groundwater are established for sources in OTA Categories III, IV, V, and VI (refer to ch. 2, table 5).
- Explicit regulatory requirements are specified for some sources in Categories I and II:
  - —*Category I:* Land application of hazardous wastes (under RCRA).
  - —*Category II:* Hazardous waste landfills, surface impoundments, waste piles, and land treatment areas (under RCRA); radioactive disposal sites (under the Atomic Energy Act); and uranium mill tailings sites (active sites under UMTRCA).
- **Only two of the programs containing corrective action regulatory provisions establish explicit cleanup standards: RCRA and UMTRCA.** The standards are based on the specified groundwater protection standard, which includes the substances to be monitored, concentration limits, the point of compliance, and the compliance period (see app. E); corrective actions are not required beyond the downgradient facility property boundary (see app. G).
- **Six Federal statutes authorize federally funded remedial action programs but none of the programs specifies cleanup standards.** Rather, the selection of a remedy under these programs (e.g., CERCLA and inactive sites under UMTRCA) is based on protection of health and the environment, costs, technical feasibility, the uses of an aquifer, and availability of alternative water supplies.

Photo credit: Office of Technology Assessment

Corrective action team wears protective clothing as they drill a recovery well.

FEDERAL GOVERNMENT EXPERIENCE

Federal agency experience with respect to the site-specific design and implementation of corrective actions is limited relative to the total number of individual sites sources identified as requiring remedial action. In addition, little of the experience relates specifically to the cleanup of contaminated groundwater. Examples of federally funded corrective action programs follow:

- Remedial actions under CERCLA can be undertaken only at sites on the National Priorities List (NPL) (see app. G). As of Sep-

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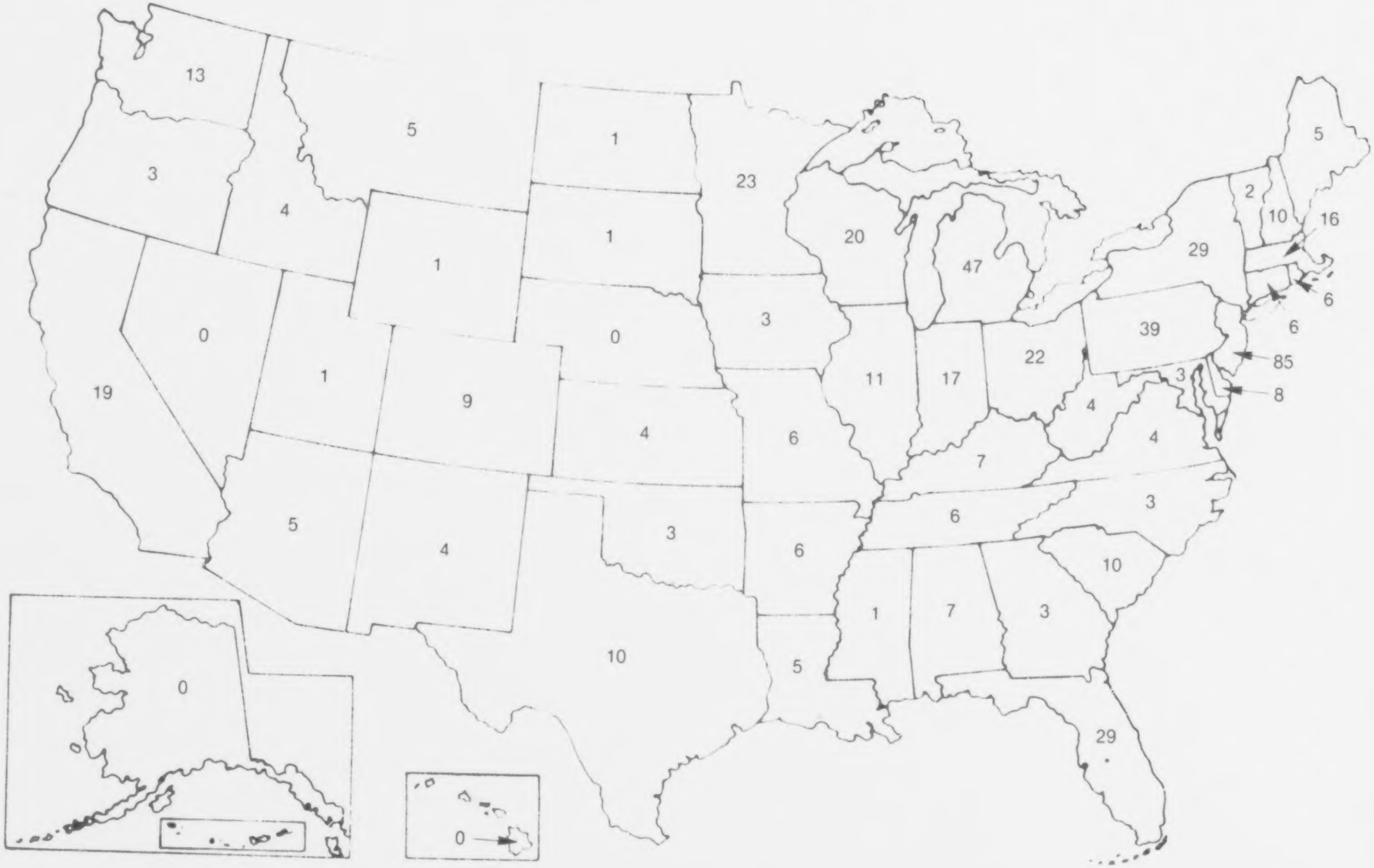
[2] Neither the National Environmental Policy Act nor the Water Research and Development Act are concerned with corrective action for specific sources; they are thus omitted from table 36.

National Priorities List Update #1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Credit: EPA, 1984b

The National Priorities List identifies target sites for remedial action under the Comprehensive Environmental Response, Compensation, and Liability Act. This map shows the number of sites in each State as of September 1984. (Additional sites are located in American Samoa (1), Marianas (1), Guam (1), Puerto Rico (8), and the Pacific Trust Territories (1).)

tember 1984, 538 uncontrolled hazardous waste sites were listed for priority action; EPA projects that the NPL could eventually contain between 1,400 and 2,200 sites (EPA, 1984a, 1984b).[3] Groundwater contamination has been detected at 410 of the listed sites.[4] As of July 1984, remedial actions had been completed at only six sites on the NPL (U.S. House of Representatives, 1984); and of these six, none involved the cleanup of contaminated groundwater. Engineering studies are underway or have been completed at 258 NPL sites, and construction has begun at more than 60 sites using Federal funds (EPA, 1984a).

- Under its Installation Restoration Program (IRP),[5] the Department of Defense has inventoried 911 installations and identified 200 that may require remedial action. As of August 1983, site investigations to confirm contamination problems had been completed at 32 sites, remedial actions at two sites had been completed, and an additional 16 actions were under way. Data on the actual number of sites contaminating groundwater were not available (Daley, 1983).
- UMTRCA led to the designation of 25 inactive uranium mill tailings sites in need of remedial action. Preliminary engineering studies indicate that groundwater contamination either has occurred or has the potential to occur at all of the sites. To date, the Department of Energy has not selected remedial actions for any of the designated UMTRCA sites, although options have been formally proposed for two sites (Baublitz, 1983).

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[3] EPA was reported to have added 244 sites to the NPL on Oct. 3, 1984 (*Washington, Post*, 1984). CERCLA requires that EPA update the NPL at least annually (Section 105 (B) of the National Contingency Plan).

[4] This figure is based on the 546 sites originally placed on or proposed for the NPL (EPA, 1983a, 1983b). A detailed assessment by an EPA consultant of data collected for 86 (of the 546) sites indicates that on-site groundwater contamination has been detected at over 60 percent of them; off-site contamination has been detected at over 27 percent of the sites (Booz-Allen & Hamilton, Inc., 1983).

[5] The IRP is a DOD program similar to CERCLA for hazardous waste sites on DOD property.

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State Efforts To Correct Groundwater Contamination

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5. OTA State Survey Responses: Number of States With Programs To Correct Groundwater Contamination From Selected Sources 206

Chapter 10

State Efforts To Correct Groundwater Contamination

CHAPTER OVERVIEW

State responses to survey questions about their efforts to correct groundwater contamination are presented in this chapter. (See the section *OTA State Survey* in ch. 4 for guidance in interpreting survey results.) The following topics are discussed:

- sources of groundwater contamination for which States have corrective action programs;
- priorities for selecting sites for action; and
- use of, preference for, and problems with corrective action techniques.

Additional information on State strengths, problems, and types of desired Federal assistance related to corrective action is found in chapter 4.

The conclusions that follow are drawn from this information.

Most States are working to correct contamination problems. But State efforts vary in terms of the sources that are addressed and the process for site selection. Further, State efforts to correct groundwater contamination are generally at *an early stage of development* in that relatively few States have formalized their approaches to corrective action.

The States are using a wide variety of techniques, and many techniques are used together. With the possible exception of source removal (for the cases where sources can be identified and removed), the States have few preferences among individual (or categories of) corrective techniques. In making decisions, the States are concerned about the costs of implementation and maintenance, the time required for implementation and achievement of desired results, and the degree of certainty about how well a technique will perform.

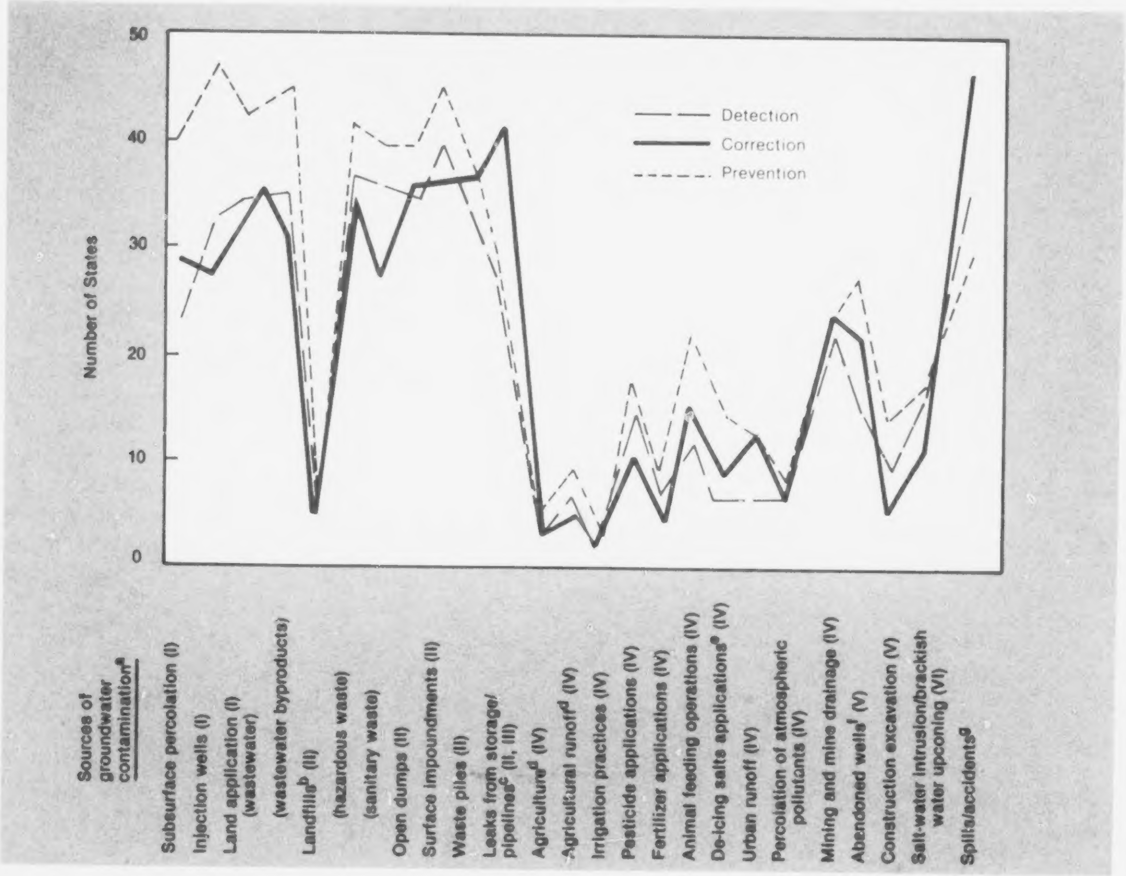
Most States have technical, legal, or institutional problems in undertaking corrective action. Although the States want Federal assistance in overcoming technical and institutional problems, most States do not want Federal assistance with their legal problems, particularly those involving water rights. Water rights issues often complicate the correction of groundwater contamination problems.

STATE CORRECTIVE ACTION PROGRAMS FOR SOURCES

Many States have programs to correct groundwater contamination from a variety of sources, as shown in figure 5. The highest number of States have programs to correct spills and accidents and leaks from storage facilities and pipelines. **Overall, more States have programs to correct sources in OTA Categories I, II, and III than to correct Categories IV, V, and VI sources** (refer to ch. 2, table 5). There appears to be no correlation between the number of States with programs for a particular source and the pervasiveness of that source either nationally or regionally. (See ch. 2 for a discussion of the location of sources.)

In some States, correction programs are established for sources although there are no detection programs for those same sources. The implication is that the need for corrective action is often iden-

Figure 5.—OTA State Survey Responses: Number of States With Programs To Correct Groundwater Contamination From Selected Sources



See fig. 2 for footnotes a through g.

SOURCE: Office of Technology Assessment.

tified as a result of complaints or other reports of concern rather than from any kind of systematic investigation. Sources for which the highest number of States have correction but not specific detection programs include: spills and accidents, leaks from storage facilities and pipelines, feedlots, application of pesticides and herbicides, abandoned wells, waste piles, and subsurface percolation.

SELECTING SITES FOR CORRECTIVE ACTION

The States consider a variety of factors in their decisions to undertake corrective action at one contaminated site as opposed to another, as shown in table 37. Severity of the problem was identified by the highest number of States, but State definitions of severity vary. The States define severity in terms of: the characteristics of the aquifer, substances, or site; uses of the groundwater; impacts of contamina-

Table 37.—OTA State Survey Responses: Factors Used By States To Determine Which Contaminated Sites To Address

Factors	Number of States
Formal criteria	24
Severity of the problem	45
Order in which contamination is detected	32
Public pressure	39
Availability of special funding	37
Sites where source and responsible party are identified	38

SOURCE: Office of Technology Assessment.

tion; reason for detection; and/or availability of water supply alternatives.

Some States have developed formal criteria for determining the sites to consider. Some use ranking systems developed by the Federal Government (e.g., MITRE Hazard Ranking System); others have developed their own ranking systems. Some have no formal ranking systems but use State regulatory definitions (e.g., groundwater quality standards) to determine which sites warrant action.

Differences in selection criteria may result in very different corrective action decisions among the States—a site may qualify for corrective action in one State, but a similar site in another State may be of a lower priority. More detailed analysis of State decisionmaking and resources (e.g., funds and staff) is necessary to determine whether the differences in priorities and approaches to site selection result in different levels of groundwater protection among the States.

Most State efforts to correct groundwater contamination are in early stages of development. This point is apparent from a lack of formal criteria for selecting sites for corrective action in many States and from the lack of formal criteria, written guidelines, or procedures in a majority of States to: 1) establish cleanup standards for corrective action (16 States have formalized approaches); 2) respond when quality standards are violated (19 States have formalized procedures, although the procedures do not cover all potential sources of contamination); and 3) respond when there is no quality standard for the substances found in groundwater (17 States have formalized procedures). Any formal criteria that have been established differ among the States.

STATE USE, PREFERENCES, AND PROBLEMS WITH CORRECTIVE ACTION ALTERNATIVES

Use and Preferences

The use of and preference for various techniques to correct contamination are summarized in table 38. The most notable point about the table is that the States are using or considering the use of a wide variety of techniques. That many techniques are used together is consistent with the technical limitations of these methods described in chapter 8. Most States are working to correct at least some of their identified groundwater contamination problems. OTA did not obtain information on either the extent to which all known incidents are being addressed or the effectiveness of the corrective actions that are being undertaken.

Preferences for specific techniques were noted by 40 States. Four States did not specify preferences for individual techniques, noting that preferences depend on such site conditions as source, substances, and aquifer characteristics. Two States said that it is too soon to know which techniques they prefer.

No individual technique is preferred by many States. Source removal (a management technique) is preferred by the highest number. The actual number of States preferring it may be higher because the OTA survey did not ask specifically about the use of this option.

Preferences for techniques relate primarily to the low cost and/or the expected effectiveness of a tech-

Table 38.—OTA State Survey Responses: Use and Preferences for Corrective Action Techniques

Technique	Number of States: Using	Number of States: With preference for use[a]
Containment:		
Slurry wall	29	1
Sheet pile	10	0
Grouting	18	0
Geomembrane	NQ[b]	NQ
Clay Cutoff	NQ	NQ
Liner[c]	47	1
Natural containment	36	2
Surface sealing	35	1
Diversion ditches	41	0
Hydrodynamic control[d]	24	5
Technique not specified	2	7
Total number of States responding	48	15
Withdrawal:		
Pumping	44	5
Gravity drainage	31	1
Withdrawal enhancement	NQ	NQ
Gas venting[e]	29	0
Excavation	41	3
Technique not specified	3	11
Total number of States responding	47	17
Treatment:		
Skimming	34	0
Filtration	28	1
Ultrafiltration	13	0
Reverse osmosis	17	1
Air stripping	34	2
Steam stripping	NQ	NQ
Precipitation/clarification/coagulation	NQ	NQ
Treatment (cont'd):		
Ion exchange	25	0
Adsorption	34	0
Electrodialysis	NQ	NQ
Chemical transformation	NQ	NQ
Biological transformation	NQ	NQ
Incineration	NQ	NQ
Technique not specified	7	14
Total number of States responding	43	16
In-situ rehabilitation:		
Biological degradation	20	1
Chemical degradation	20	0
Water table adjustment	40	3
Natural process restoration	33	4
Technique not specified	3	2
Total number of States responding	47	10
Management:		
Limit/terminate aquifer use	38	5
Develop alternative water supply	44	6
Purchase alternative water supply	32	1
Municipal treatment[f]	NQ	1[g]
Point of end-use treatment[f]	32[h]	0
Source removal	NQ	11[g]
Monitoring	47	8
Health advisories	46	3
Accept increased risk	NQ	NQ
Technique not specified	1	1
Total number of States responding	49	21

[a] Nine States noted that they had few or no preferences for techniques—either because of having relatively little experience with implementing corrective actions or because preferences were site specific. Four additional States had no preferences but did not provide an explanation. Some States listed more than one preference.

[b] NQ—OTA did not specifically question the States about this option.

[c] Responses primarily reflect the use of liners for prevention of groundwater contamination (e.g., in the design of new facilities); liners are rarely used for corrective action purposes.

[d] OTA used the term plume management in the questionnaire to the States rather than hydrodynamic control.

[e] OTA used the term gas migration control in the questionnaire to the States rather than gas venting.

[f] These treatment techniques are listed under Management to reflect who is responsible for the action and whether treatment occurs before or after water distribution.

[g] Although OTA did not specifically question the States about use of this option, some States noted a preference for it.

[h] Several States noted that this was a private option and not one that the State would implement.

SOURCE: Office of Technology Assessment.

nique or combination of techniques. These reasons were given for all categories of corrective action techniques. Other reasons given, mostly for preferring management options, relate to the lack of either resources or effective alternatives to clean up the contamination, the relatively short time usually available for implementation, and the absence of clear State authority to implement other techniques.

Agencies within a State may have different preferences for corrective action techniques. These differences may reflect agency missions, knowledge of technical options, and the problems that each confronts. For example, in one State, the health agency prefers to develop alternative sources, the water quality agency prefers withdrawal and treatment techniques, and the industry regulatory agency prefers containment options.

Photo credit: U.S. Environmental Protection Agency

Prior to removing a potential source of contamination, such as deteriorating drums, contents must be identified to evaluate disposal options.

Problems With Corrective Action

Thirty-one States described problems with implementing corrective action techniques. Of the States that did not describe problems, five specifically noted that experience is too limited to evaluate the techniques. Other problems are more closely related to detection and hydrogeologic investigations (e.g., with contaminant transport models and identifying sources of contamination and responsible parties) and are discussed in chapter 7.

Table 39 classifies the problems associated with corrective action alternatives as technical, institutional, and legal and provides examples of each. General findings are:

- The States experience a variety of problems in implementing techniques for corrective action, and different States have different problems.
- **More States noted technical problems than legal or institutional problems.** This situation contrasts with the reported problems with hydrogeologic investigations, which are mostly institutional (see ch. 7). However, specific legal problems with water rights and general authority were also listed by a relatively large number of States regarding corrective action.

Photo credit: State of Florida Department of Environmental Regulation

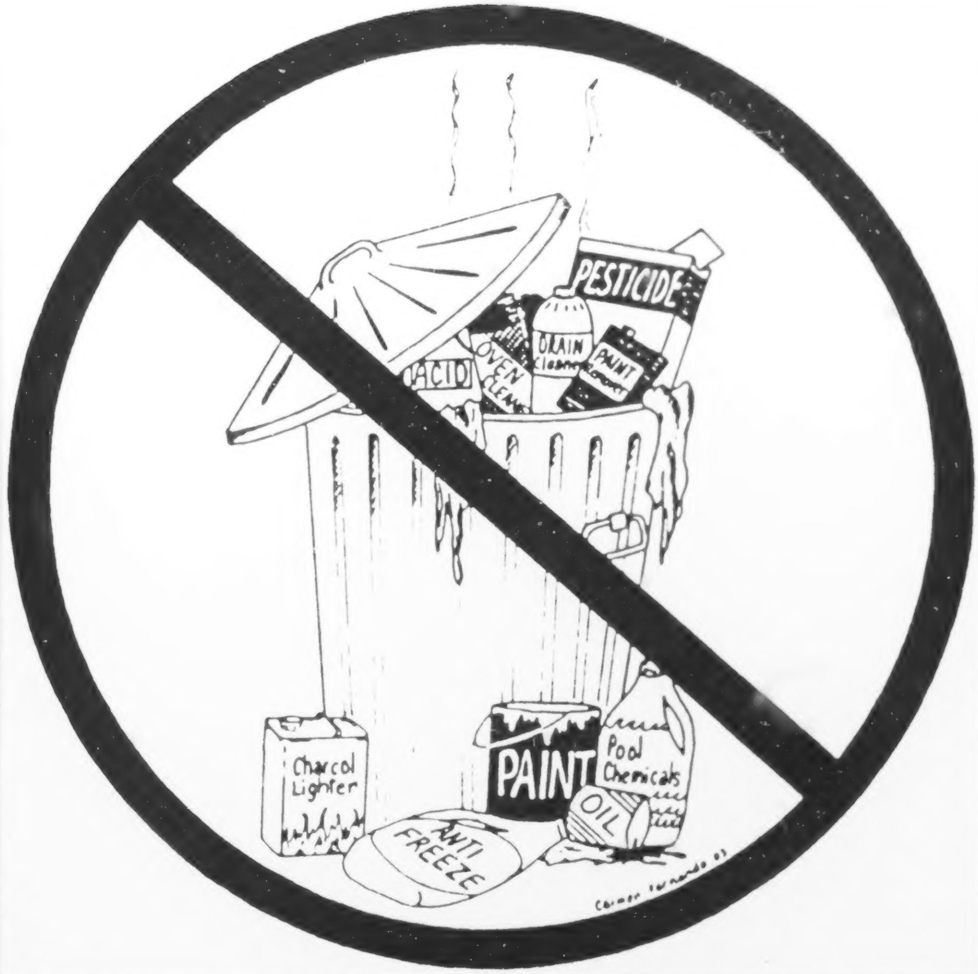
When contaminated drinking water wells are closed, water must be obtained from other sources.

Table 39.—OTA State Survey Responses: State Problems With Corrective Action Techniques

Number of States	Types of problems	Examples of problems
Technical problems:		
10	High cost of techniques	• Expense of treatment techniques for removing some organics • Expense of developing alternative water supplies • Expense of correcting salt-water contamination in agricultural areas
6	Site constraints associated with techniques	• Techniques unavailable for karst environments • Limitations on achievable withdrawal rates
1	Difficulties implementing techniques	• Difficulties in designing and installing liners
4	Lack of knowledge on setting standards for performance	• Lack of information on health and environmental impacts of many contaminants
4	Uncertainty over effectiveness of techniques	• Inability to predict technical performance
3	Adverse impacts of some techniques	• Increased contaminant migration caused by well closings and cessation of pumping • Impacts on air quality caused by air stripping
3	Intensive data and monitoring requirements	• Difficulties in identifying sources of contamination • Continued presence of contaminants after corrective action has been undertaken necessitates continued monitoring
21	Total States reporting technical problems	
Institutional problems:		
6	Lack of funds	• Scope of State activities constrained
3	Inadequate technical expertise	• Lack of staff with sufficient technical knowledge
3	Inadequate regulations and program implementation	• Lack of standards for determining cleanup objectives • Inadequate enforcement
3	Lack of interagency coordination	• Overlapping authority among agencies • Difficulties in coordinating with Federal agencies
1	Unavailability of equipment	• Shortage of drilling rigs and lack of geophysical equipment
2	Public resistance	• Public unwillingness to use water after cleanup
11	Total States reporting institutional problems	
Legal problems:		
10	Lack of authority—water rights	• Difficulties in obtaining information on water use and pumping schedules • Inability to control or restrict water uses that may influence alternatives involving pumping • Difficulties in obtaining alternative water supplies
8	Lack of authority—other	• Lack of regulatory jurisdiction over potential sources of contamination (e.g., underground storage tanks) • Difficulties in obtaining property access
2	Liability concerns	• Potential for damage suits if State supplies alternative water supply (e.g., bottled water) that turns out to be contaminated
16	Total States reporting legal problems	
31	Total number of States noting problems	

SOURCE: Office of Technology Assessment.

Prevention


PESTICIDE
DRAIN Cleaner
PAINT Remover
ACID
OVEN CLEANER
Charcol Lighter
PAINT
Pool Chemicals
OIL
ANTI FREEZE

Chapter 11

Federal Efforts To Prevent Groundwater Contamination

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Chapter 11

Federal Efforts To Prevent Groundwater Contamination

CHAPTER OVERVIEW

Activities authorized by Federal statutes related to the prevention of groundwater contamination are described in this chapter. They address prevention in terms of:

- sources of contamination;
- groundwater recharge areas; and
- potential contaminants.

The Federal Government does not have a formal plan or comprehensive strategy to prevent contamination. For example, programs for sources—for design and operation, siting, and post-closure—do not use a consistent definition of the groundwater resource to be protected and do not systematically address the contamination potential of sources. The program for protecting recharge areas is not comprehensive because the designation of such areas is optional and only certain potentially contaminating projects are restricted. To date, the application of provisions that regulate the production and use of potential groundwater contaminants to prevent contamination has been limited.

PREVENTION OF CONTAMINATION BY SOURCES

Federal statutes and programs address prevention of contamination from sources in terms of three types of factors:

1. the scope of the groundwater resource covered (e.g., groundwater in general or drinking water supplies);
2. the specific sources addressed and the type of program (e.g., for design and operation—these may be either mandatory or voluntary); and
3. the performance requirements specified (e.g., for the siting of sources and their closure).

Table 40 summarizes the provisions of Federal programs in terms of these factors.[1] Federal monitoring and corrective action requirements are noted in the table but they are discussed in chapters 6 and 9, respectively.

Scope of the Groundwater Resource Addressed

The scope of groundwater resources covered by Federal programs is an important consideration in preventing groundwater contamination. However, Federal programs are not consistent in defining the resource covered and the extent of degradation permitted. Table 40 (column 3) summarizes the way in which groundwater is addressed by Federal programs:

- **The scope of groundwater resources covered by Federal programs is not consistent.**
  —Four programs (authorized by AEA for low-level waste sites, FLPMA and associated mining laws, SMCRA, and TSCA) address *groundwater in general.*
  —Two programs are concerned with the *uppermost aquifer* (authorized by RCRA-Subtitle C and UMTRCA).
  —Three programs cover *underground drinking water supplies* (authorized by RCRA-Subtitle D, SDWA, and CWA-Section 405).

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[1] Four statutes included in ch. 3 are not applicable to this discussion and thus are not included in table 40: NEPA and WRDA do not establish requirements for sources; CERCLA and the Reclamation Act (RA) are not included because they provide for remedial actions, not preventive measures.

Table 40.—Federal Provisions To Prevent Groundwater Contamination From Sources

Statute	Publication date of regulations	Relationship to groundwater	Type of program and sources addressed[a]	Siting requirements	Monitoring requirements[b]	Corrective action requirements[c]	Post-closure requirements
Atomic Energy Act	NRC regulations (10 CFR 61)—12/27/82 (EPA has not promulgated environmental protection standards)	Radioactive material released into groundwater must not exceed levels specified in the regulations.	Design and operating standards are specified for low-level waste disposal sites.	Disposal sites must provide sufficient depth to the water table to prevent groundwater intrusion into the wastes. Hydrogeologic units used for disposal shall not discharge groundwater to the surface within the disposal site. Other requirements relate to seismic and other tectonic activity, flooding, location of natural resources, and population growth and development.	Yes	Yes	Active institutional controls (e.g., monitoring) may not be relied on for more than 100 years (the exact period to be determined by the NRC on a case-by-case basis).
	NRC proposed regulations (10 CFR 60)—7/8/81, 46 FR 35280 EPA proposed environmental protection standards (40 CFR 191)—12/29/82, 47 FR 58196[d]	Geologic repositories include the operations area and the geologic setting (the geologic, *hydrologic*, and geochemical systems that provide isolation of the waste).	Design and operating standards are specified for geologic repositories for high-level radioactive wastes.	The geologic setting must exhibit structural, tectonic, hydrogeologic, geochemical, and geomorphic stability. Groundwater travel times (prior to waste deposition) through the geologic setting (i.e., the area that provides isolation of wastes) to the accessible environment must be at least 1,000 years.	Yes	None	Disposal systems must be designed to prevent releases of specific amounts of radioactive material for 10,000 years after disposal. Active institutional controls must not be relied on beyond a few hundred years.
Clean Water Act — Section 201	EPA Criteria—2/11/76, 41 FR 6190 (EPA construction grant regulations are specified in 40 CFR 35)	Groundwater is separated into three categories concerning the land application of wastewater: — If groundwater is a potential drinking water supply, the National Interim Drinking Water Regulations (NIDWRs) must not be exceeded. If background levels are higher than NIDWRs, they must not be exceeded.	Criteria for best practicable waste treatment technology for land application of wastewater must be met by applicants for construction grant funds (for sewage treatment works).	None	Yes	Yes	None

Table 40.—Federal Provisions To Prevent Groundwater Contamination From Sources— continued

Statute	Publication date of regulations	Relationship to groundwater	Type of program and sources addressed[a]	Siting requirements	Monitoring requirements[b]	Corrective action requirements[c]	Post-closure requirements
Clean Water Act — Section 201 (cont'd)		— If groundwater is used as a drinking water supply, the conditions above must be met (except that levels for biological contaminants must not be exceeded in the supply if water is not disinfected). — If groundwater is used for purposes other than drinking water, criteria are established on a case-by-case basis.					
— Section 208	EPA State grant regulations (40 CFR 35, Subpart G)—5/23/79	The program is oriented to surface water; however, States are authorized to undertake groundwater activities to the extent practicable.	Funds are authorized for States to develop water quality management plans. State plans provide for development of activities (e.g., Best Management Practices) related to certain non-point sources.[e]	Not applicable	Not applicable	Not applicable	Not applicable
— Section 311	EPA regulations (40 CFR 112)—12/11/73	The program is oriented to surface water protection; groundwater is not directly addressed.	Spill Prevention and Countermeasure Control (SPCC) Plans must be prepared for above-ground and underground tanks of a specified size containing oil. The plan must describe design and operating conditions.	None	None	None	None
— Section 404	EPA regulations (40 CFR 230)—12/24/80	Protection is oriented to wetlands protection; groundwater is not directly addressed.	Permits must be obtained to dispose of dredged or fill material. Guidelines to be applied in the review of proposed discharges are specified.	General guidance is provided that relates to the selection of disposal sites such that the potential for erosion, slumping, or *leaching* of material into surrounding aquatic ecosystems will be reduced.	None	None	None

Table 40.—Federal Provisions To Prevent Groundwater Contamination From Sources— continued

Statute	Publication date of regulations	Relationship to groundwater	Type of program and sources addressed[a]	Siting requirements	Monitoring requirements[b]	Corrective action requirements[c]	Post-closure requirements
— Section 405	EPA Criteria (40 CFR 257)–9/13/79	For underground drinking water sources, background levels or National Interim Drinking Water Regulations (if higher than background) must not be exceeded beyond the site boundary or an alternative boundary established on a case-by-case basis.	Criteria established for solid waste landfills must be met for land application of sludge by owners or operators of publicly owned treatment works.	None	Yes	Yes	None
Coastal Zone Management Act	NOAA State grant regulations (15 CFR 923)—3/28/79	The States are required to determine whether there are areas requiring special management to protect aquifers and their recharge areas and areas that might be subject to significant hazard due to salt-water intrusion (if development were permitted).	Funds are provided to the States for the development of coastal zone management plans. Plans may include provisions that address salt-water intrusion.	Not applicable	Not applicable	Not applicable	Not applicable
Federal Insecticide, Fungicide, and Rodenticide Act[f]							
— Section 3	EPA regulations (40 CFR 162)—7/3/75	Criteria for determining unreasonable adverse effects do not explicitly address groundwater.	The use of pesticides that may cause unreasonable adverse effects on the environment can be restricted or prohibited.	Use restrictions may be established for a pesticide.	None	None	None
— Section 19	EPA regulations (40 CFR 165)—5/1/74	Regulations refer to water systems; groundwater is not explicitly addressed.	Recommended procedures are established for storage areas for pesticides.	Facilities should be located where flooding is unlikely and where soil and hydrogeologic characteristics will prevent contamination of any water system by runoff or percolation.	None	None	None
Federal Land Policy and Management Act							
— Mineral Leasing Act of 1920 and Materials Act of 1947	BLM regulations (43 CFR 23)—1/18/69	Regulations specify that a plan of operations must be developed that includes measures to prevent or control groundwater pollution. State and Federal water quality standards must be met.	Requirements for mining of leasable minerals on Federal lands are to be specified in the plan of operations.	Operations may be prohibited or restricted in areas if the regulatory authority determines that *water quality* will be lowered below State standards or levels set by DOI. Groundwater is not explicitly mentioned.	None	None	Performance bond must be filed to cover reclamation activities.

Table 40.—Federal Provisions To Prevent Groundwater Contamination From Sources— continued

Statute	Publication date of regulations	Relationship to groundwater	Type of program and sources addressed[a]	Siting requirements	Monitoring requirements[b]	Corrective action requirements[c]	Post-closure requirements
— U.S. Mining Laws	BLM regulations (43 CFR 3800)—3/3/80	Groundwater is not directly addressed in the regulations; however, State and Federal water quality standards must be met.	Requirements for mining of locatable minerals on Federal lands are to be specified in the plan of operations.	None	None	None	Performance bond must be filed to cover reclamation activities.
— Geothermal Steam Act	BLM regulations (30 CFR 270)—6/27/79 and 6/30/82[g]	Regulations specify that a plan of operations must be developed which includes measures to prevent or control groundwater pollution. State and Federal water quality standards must be met.	Requirements for development of geothermal steam on Federal lands are to be specified in the plan of operations.	None	Yes	None	None
Hazardous Liquid Pipeline Safety Act	DOT regulations (49 CFR 195)—7/27/81 as amended	The objective of the regulations is to prevent leakage. However, groundwater is not directly addressed.	Design and operating standards are specified for pipelines used to transport hazardous liquids.	None	None	None	None
Hazardous Materials Transportation Act	DOT regulations (49 CFR Subtitle B, Subchapter C)—4/15/76 as amended	The objective of the regulations is to protect against risks to life and property. However, groundwater is not directly addressed.	Design and operating standards are specified for transportation of hazardous materials and hazardous wastes.	None	None	None	None
Resource Conservation and Recovery Act							
— Subtitle C	EPA regulations (40 CFR 264)—7/26/82 Note: Final regulations have not been promulgated for covered underground tanks or for some open burning and detonation sites.	Regulations specify that hazardous substances entering groundwater (in the uppermost aquifer) must not exceed background levels, the Maximum Contaminant Levels for 14 constituents specified by the National Interim Drinking Water Regulations (if higher than background), or alternative concentration limits (established on a case-by-case basis) at the compliance point.	Design and operating standards are specified for hazardous waste treatment, storage, and disposal facilities (e.g., landfills, surface impoundments, waste piles, and land treatment areas).	Facilities must not be located in areas subject to flooding or seismic conditions.	Yes	Yes	Specified activities (e.g., groundwater monitoring and operation of leachate collection system) must be continued for 30 years after closure unless the time period is increased or or decreased by the regulatory authority.

Table 40.—Federal Provisions To Prevent Groundwater Contamination From Sources— continued

Statute	Publication date of regulations	Relationship to groundwater	Type of program and sources addressed[a]	Siting requirements	Monitoring requirements[b]	Corrective action requirements[c]	Post-closure requirements
— Subtitle D	EPA regulations (40 CFR 257)—9/13/79	The criteria specify that for underground drinking water sources, background levels or the National Interim Drinking Water Regulations (if higher than background) must not be exceeded beyond the application boundary or an alternative boundary established on a case-by-case basis.	Funds are authorized for States to develop optional State solid waste programs. Specified Federal criteria for sanitary landfills must be met by State program.	None	None	None	None
Safe Drinking Water Act							
— Part C (UIC Program)	EPA regulations (40 CFR 146)—6/24/80 as amended Note: Regulations have not been promulgated for certain wells.[i]	Regulations specify that it must be demonstrated that activities will not be conducted in a manner that allows movement of contaminants into an underground source of drinking water (defined as an aquifer or its portion that supplies any public water system or contains sufficient water to supply a public water system and that currently serves as a drinking water supply or contains fewer than 10,000mg/l TDS). Aquifers may be exempted if they are not currently drinking water supplies, cannot and will not be supplies in the future. or contain 3,000-10,000 mg/l TDS and are not reasonably expected to supply a public water system.	Design and operating standards are specified for underground injection wells.	None	Yes	None	None[h]
Surface Mining Control and Reclamation Act	OSM regulations (30 CFR 816 and 817)—revised 9/26/83 (Regulations were first published in 1979)	Regulations specify that groundwater quality must be protected by handling earth materials and runoff in a manner that minimizes acidic,	Requirements are specified in operating permit for surface coal mining and underground coal mining (for surface effects).	None	Yes	Yes	Performance bond must be filed to cover reclamation activities.

Table 40.—Federal Provisions To Prevent Groundwater Contamination From Sources— continued

Statute	Publication date of regulations	Relationship to groundwater	Type of program and sources addressed[a]	Siting requirements	Monitoring requirements[b]	Corrective action requirements[c]	Post-closure requirements
		toxic, or other harmful infiltration to groundwater systems and by managing excavations and other disturbances to prevent and control the discharge of pollutants into groundwater. State and Federal water quality standards must be met.					
Toxic Substances Control Act[f] — Section 6	EPA regulations (40 CFR 761)—5/31/79	The objective of regulations is to ensure against an unreasonable risk of injury to health or the environment (e.g., water) from the manufacture, processing, distribution, use, or disposal of a chemical substance or mixture.	Design and operating standards are specified for PCB disposal sites.	Facilities must be located in areas of low to moderate relief and must avoid floodplains, shorelands, and groundwater recharge areas. Bottom of landfill must be 50 feet from historical high water table.	Yes	None	Operating records must be retained for 20 years after closure.
Uranium Mill Tailings Radiation Control Act	NRC regulations (10 CFR 40)—10/3/80 EPA regulations (40 CFR 192)—10/7/83, 48 FR 45926	Same as RCRA—Subtitle C (except that levels for certain radioactive substances are specified).	Design and operating standards are specified for uranium mill tailings disposal sites (same as RCRA Subtitle C requirements for surface impoundments).	NRC requirements specify that the selection process must consider hydrologic and other conditions as they contribute to continued immobilization and isolation of contaminants from usable groundwater sources. EPA regulations do not establish siting requirements.	Yes	Yes	Long-term surveillance is specified by NRC on a case-by-case basis. EPA regulations require that sites be developed to be effective for 1,000 years to the extent reasonably achievable and in any case for at least 200 years.

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[a] See table 13 and app. H for additional information on sources, types of programs, and design and operating requirements.
[b] See table 30 and app. E for additional information on monitoring requirements.
[c] See table 36 and app. G for additional information on corrective action provisions.
[d] The provisions cited in the table are EPA's proposed protection standards.
[e] Provisions apply to non-point sources including irrigation return flows, agricultural sources, livestock areas, mine runoff, salt-water intrusion, and construction activity.
[f] See the text for a more detailed discussion of FIFRA and TSCA.
[g] Regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.
[h] There are plugging requirements at closure.
[i] Regulations have not been promulgated for Class IV and V wells under the UIC Program; see app. H and 40 CFR 146.

SOURCE: Office of Technology Assessment.

- —One program (under Section 201 of CWA) *separates groundwater into three categories*—drinking water supplies, potential drinking water supplies, and groundwater used for other purposes—with different standards for each category.
- —The programs authorized by five statutes *do not directly address* groundwater in any way (CWA—Sections 311 and 404, CZMA, FIFRA, HLPSA, and HMTA).
- —The requirements for selecting geologic repositories for high-level radioactive wastes (under AEA) include *surrounding hydrogeologic systems* as part of the repository.

- **The extent of degradation permitted by Federal programs is not consistent.**
  - —Under the Subtitle C program of the Resource Conservation and Recovery Act (RCRA, which addresses the uppermost aquifer), the Environmental Protection Agency (EPA) may establish alternative concentration limits on a case-by-case basis (instead of requiring that groundwater contamination not exceed background levels or Maximum Contaminant Levels). EPA regulations specify the factors that must be considered in approving the alternative concentration limits.[2] However, decisions are to be made by permit writers on a site-specific basis.
  - —Under the Underground Injection Control Program of the Safe Drinking Water Act (SDWA), certain aquifers may be exempted. Thus, underground injection into those aquifers is not controlled.

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[2] See 40 CFR 264.94(b).

Photo credit: CECOS International

Liners and leachate control systems are included in the design and operating requirements for hazardous waste landfills and surface impoundments under Subtitle C of RCRA. This photograph shows a synthetic and clay-lined hazardous waste disposal facility prior to use.

Types of Programs and Sources Addressed

The principal type of program related to the prevention of contamination from sources is for design and operation. As indicated in chapter 2, potential sources of contamination have different characteristics for releasing substances (e.g., point v. non-point discharges) which necessitate different design specifications and operating procedures to prevent groundwater contamination. Programs may be either mandatory or voluntary; and they are specified for particular sources of contamination. Design and operating requirements are summarized in table 40 (column 4) and described in detail in appendix H in relation to each Federal program and OTA source categories (refer to ch. 2, table 5). The following observations can be made about the types of programs that have been developed. (Note that the technical adequacy of these programs has not been evaluated in this study.)

- Mandatory design and operation requirements apply to *subsets* of sources within Categories I, II, III, and V. As noted in chapter 3, the sources addressed by programs with mandatory requirements are, for the most part, associated with hazardous wastes or other toxic materials.
- With the exception of certain mining activities and the application of certain pesticides, sources in Category IV are not subject to mandatory requirements. However, Best Management Practices or recommended procedures have been developed for some of these sources.
- There are no mandatory requirements for any sources in Category VI.

It is significant that many of the programs' requirements were established fairly recently. Table 40 (column 2) indicates that the majority of regulations were published within the past 5 years. Thus, the impacts of some of these programs on the prevention of groundwater contamination cannot yet be ascertained. Further, despite the fact that programs have been authorized by Federal legislation for certain sources, **regulations specifying design and operating (as well as monitoring and corrective action) requirements have not been promulgated for certain sources.** These sources include:

- covered underground tanks (under RCRA);
- injection wells used to dispose of hazardous wastes *into* or above underground sources of drinking water and all other injection wells *except* those used for the following purposes: disposal of hazardous or radioactive materials and other wastes (e.g., municipal or industrial) *beneath* underground sources of drinking water; wells used in association with oil and gas production; and wells used for in-situ or solution mining (under SDWA);
- open burning and detonation sites (under RCRA); and
- low-level radioactive disposal sites (under AEA).[3]

In addition, the purview of the Hazardous Liquid Pipeline Safety Act (HLPSA), which establishes requirements for interstate pipelines (used to transport petroleum products and anhydrous ammonia), includes the *storage* of liquids incidental to their movement by pipeline. Although regulations have been promulgated for pipelines, the Department of Transportation has not established requirements for storage facilities (e.g., tanks).

Performance Requirements

This study also examined the extent to which Federal programs address the prevention of groundwater contamination with performance requirements for siting new sources and post-closure. As indicated in table 40 (column 5), siting provisions for new sources are specified by six programs: high- and low-level radioactive waste programs under the Atomic Energy Act (AEA); pesticide storage provisions under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); mineral mining provisions for leasable minerals under the Mineral Leasing Act; the hazardous waste program (Subtitle C) under RCRA; the PCB disposal requirements under the Toxic Substances Control Act (TSCA); and the Nuclear Regulatory Commission

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[3] The Nuclear Regulatory Commission has issued licensing regulations for these facilities. However, EPA has not issued environmental protection standards.

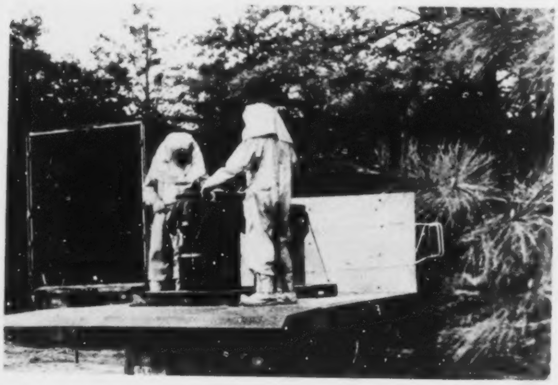

Photo credits: U.S. Environmental Protection Agency

Open burning and detonation of waste explosives are addressed under RCRA but regulations have not yet been promulgated. These photographs show white phosphorus drums being prepared for disposal . . . and their subsequent detonation.

requirements for uranium mill tailings sites established under the Uranium Mill Tailings Radiation Control Act (UMTRCA). Of the six programs, the requirements established under RCRA and the Mineral Leasing Act do not explicitly address the protection of areas vulnerable to groundwater contamination.[4]

Provisions that address any contamination that may occur after a source is no longer in use ("post-closure") are also important for the prevention of contamination. Table 40 (column 8) summarizes these provisions.[5] **Post-closure provisions are specified for a limited number of sources: disposal facilities for hazardous and certain radioactive substances and mining operations.** There is also an inconsistency between the requirements for hazardous waste facilities and high-level radioactive waste sites: in spite of the fact that many of the chemicals found in hazardous waste disposal facilities are non-degradable, a post-closure period of only 30 years has been set.[6] In comparison, it has been proposed that high-level radioactive waste disposal sites which contain radioactive substances that *do* degrade over time (e.g., half-lives of radioactive substances range from tens to more than millions of years) must be designed to prevent releases for 10,000 years.[7]

There are two additional points about the post-closure requirements in table 40 with respect to specific sources:

1. There are no post-closure monitoring requirements established for PCB disposal facilities. Thus, any groundwater contamination that may occur following closure is not likely to be detected.
2. Specific requirements have not been established for uranium mill tailings sites. Post-closure provisions will be required only at the discretion of the regulatory authority.

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[4] *Proposed* RCRA regulations issued by EPA on Dec. 18, 1978 (43 FR 59000) did contain siting requirements with respect to aquifer recharge areas, but the provisions were not adopted in the final regulations issued by the agency (40 CFR 264.18).

[5] In this assessment, reclamation activities conducted as part of mining operations are considered post-closure provisions.

[6] Although the post-closure period can be extended by the regulatory authority if necessary, it is possible that a site will appear to be secure at the end of the 30-year period but subsequently release substances into groundwater.

[7] 47 FR 58196, Dec. 29, 1982.

AQUIFER PROTECTION

A second approach of Federal statutes related to the prevention of groundwater contamination is to protect recharge areas. The Sole Source Aquifer provision of the Safe Drinking Water Act, Section 1424(e), allows the Administrator of EPA to designate the aquifers that serve as sole or principal drinking water sources and to prevent any commitments of *Federal* financial assistance to projects that may create significant hazards to public health by contaminating such aquifers.

The Sole Source Aquifer provision does not establish a comprehensive program for protecting aquifer recharge areas. The process for designating sole source aquifers is optional, and only certain projects are restricted from receiving Federal financial assistance. In addition, funding decisions are based on findings regarding the significance of the hazard posed to human health.[8]

EPA issued proposed regulations in September 1977 establishing procedures for designating sole source aquifers and reviewing projects proposed in these areas (final regulations have not been published by EPA).[9] The proposed regulations define several key terms used in this section of the statute:

- *A sole or principal source aquifer* is defined as one which supplies 50 percent or more of the drinking water for an area. The proposed regulations also specify six factors that must be considered in deciding whether to *designate* a sole source aquifer:
  1. the availability of alternative sources of drinking water;
  2. the size of the area and population served by the aquifer;
  3. the susceptibility of the aquifer to contamination through the recharge zone;
  4. the location of the aquifer;
  5. the number of public water systems using water from the aquifer, the number of people served by the systems, and the treatment provided by the systems; and
  6. such other factors as are deemed relevant.[10]
- *A significant hazard to public health* means any level of a contaminant: a) which causes or may cause the aquifer to exceed any Maximum Contaminant Level set forth in any promulgated National Primary Drinking Water Regulation at any point where the water may be used for drinking purposes or which may otherwise adversely affect human health, or b) which may require a public water system to install additional treatment to prevent such adverse effects.
- *Federal financial assistance* includes any financial benefits provided directly as aid to a project by a department, agency, or instrumentality of the Federal Government in any form, including contracts, grants, and loan guarantees. Actions or programs carried out by the Federal Government itself (e.g., dredging performed by the Army Corps of Engineers) and actions performed for the Federal Government by contractors (e.g., construction of roads on Federal lands) are not included. Federal financial assistance is limited to benefits earmarked for a specific program or action and awarded directly to the program or action.[11]

As of July 1984, EPA had designated 17 sole source aquifers (see EPA, 1983, 1984).[12]

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[8] The Sole Source Aquifer provision originated as a floor amendment to the Safe Drinking Water Act. See Hemphill, 1976.

[9] 42 FR 51620, Sept. 29, 1977.

[10] 42 FR 51623.

[11] 45 FR 51621. EPA has indicated that it "will not be concerned with reviewing on an individual basis, small isolated commitments of financial assistance such as individual home mortgage loans."

[12] Designated aquifers are:

1. Edwards Aquifer, TX (petition received 1/3/75, designated 12/16/75)
2. Nassau/Suffolk Counties Long Island, NY (petition received 1/21/75, designated 6/21/78)
3. Maryland Piedmont (petition received 10/1/75, designated 8/27/80)
4. Northern Guam (petition received 11/20/75, designated 4/26/78)
5. Fresno County, CA (petition received 8/9/76, designated 9/10/79)
6. Spokane-Rathdrum Prairie, WA-ID (petition received 10/4/76, designated 2/9/78)
7. Biscayne Aquifer, FL (petition received 5/8/78, designated 10/11/79)
8. Buried Valley, NJ (petition received 1/16/79, designated 5/8/80)
9. Cape Cod, MA (petition received 3/4/81, designated 7/31/82)
10. Whidbey Island, WA (petition received 4/31/81, designated 4/6/82)
11. Camon Island, WA (petition received 4/31/81, designated 4/6/81)
12. Kings/Queens Counties, NY (designated 1/24/84)

After an area is designated as having a sole or principal source aquifer, the Regional Administrator may review any project located in that area for which Federal financial assistance is proposed. The proposed regulations specify the review procedures that must be followed by EPA.[13] Anyone may petition EPA to review a project, or EPA may initiate the review. In addition, Federal agencies are required to maintain a list of projects in the recharge or streamflow zone of a designated aquifer for which environmental impact statements (under the National Environmental Policy Act, NEPA) will be prepared. EPA has stated that "the process of project review pursuant to Section 1424(e) will be integrated as fully as possible with the review of Federal actions subject to NEPA."[14]

(footnote 12 continued)

13. Ridgewood, NJ (designated 1/24/84)
14. Upper Rockaway River Basin, NJ (designated 1/24/84)
15. Upper Santa Cruz and Avra-Altar Basin, AZ (designated 1/24/84)
16. Nantucket Island, MA (designated 1/24/84)
17. Block Island, RI (designated 1/24/84)

[13] If an area is designated, EPA must identify the boundaries of the recharge zone or streamflow source zone (or portions thereof) through which contamination could affect the area and the water body or bodies which contact the recharge zone. 42 FR 51623.

[14] 42 FR 51621.

REGULATING THE PRODUCTION AND USE OF POTENTIAL CONTAMINANTS

There are two Federal statutes that provide for regulation of the production and use of potential groundwater contaminants: the Toxic Substances Control Act and the Federal Insecticide, Fungicide, and Rodenticide Act. Both require submission of data on the environmental effects of chemicals and authorize the regulation of potential groundwater contaminants. To date, however, their use for the prevention of contamination has been limited.

Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) provides for the regulation of chemical substances and mixtures whose manufacture, processing, distribution in commerce, use, or disposal may present an unreasonable risk of injury to health or the environment.[15] Unlike other statutes analyzed in this study (e.g., RCRA and SDWA), TSCA does not focus on specific sources of groundwater contamination. However, because it encompasses all aspects of a chemical's pathway through society, including use and disposal, TSCA has the potential for directly addressing groundwater contamination (see ch. 2 for a discussion of pathways). In addition, TSCA provides a mechanism for obtaining data on the properties of certain chemicals associated with sources of groundwater contamination.

Two provisions of TSCA are most relevant to the prevention of contamination.

1. Section 5 requires that manufacturers or importers of "new" chemicals submit a premanufacture notice (PMN) to EPA 90 days before the substance enters commerce. The PMN is to include sufficient data for EPA to *determine* whether the manufacture, processing, distribution in commerce, use, or disposal of the new chemical—or any combination of such activities—will present an unreasonable risk of injury to health or the environment.[16]
2. Section 6 provides for *regulation* of the manufacture, processing, distribution in commerce, use, or disposal of chemical substances or mixtures that present or will present an un-

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[15] "Environment" is defined to include water, air, and land and the interrelationship which exists among and between these media and all living things (Section 3(5)). "Groundwater" is not explicitly mentioned.

[16] TSCA does not define "unreasonable risk." In 1979, EPA stated that it "intends to balance the magnitude of risks and social benefits associated with a chemical substance. In doing this, EPA will consider the seriousness of the risk (including the nature, extent, and reversibility of the adverse effects), the availability of alternatives to the substance and their associated risks, and the benefits (economic and otherwise) which accrue to society from the production and use of the substance." 44 FR 16243, Mar. 16, 1979.

reasonable risk of injury to health or the environment.[17]

Section 5. TSCA specifies that the PMN submitted to EPA by a manufacturer *must* include information regarding the chemistry of the new substance, proposed uses, the amounts to be manufactured or processed, the byproducts, the number of workers to be exposed and the duration of exposure, and methods of disposal. General classes of information are also to be submitted to EPA, including any available test data in the possession or control of the manufacturer related to environmental and health effects and a description of any other data, insofar as known to the manufacturer or reasonably ascertainable.[18] EPA can then take one of four actions following the review of a PMN: 1) allow the substance to be manufactured without restriction; 2) allow the substance to be manufactured for specified uses (EPA would have to be notified about other uses); 3) if a decision about unreasonable risk cannot be reached because of the lack of information, delay the manufacture, processing, distribution, use, or disposal until additional information is developed; or 4) regulate the manufacture, processing, distribution, use, or disposal of the substance.

A previous OTA study reviewed the information contained in the 740 PMNs submitted to EPA from July 1, 1979 to June 1981 and in June 1982 (OTA, 1980). The study found that 62 percent of the PMNs reported all the information specified by TSCA (e.g., chemistry, proposed uses, amounts, byproducts, exposure, and disposal methods). However, only 10 percent of the PMNs reported any information from tests used to estimate environmental effects. Physical-chemical data most directly related to predicting the behavior of chemicals in groundwater—density, vapor pressure, solubility (in water), and partition coefficient—were reported, respectively, on 19 percent, 24 percent, 42 percent, and 4 percent of all PMNs (OTA, 1983; Gough, 1983). In addition, although approximately 50 percent reported toxicity information, only 17 percent had any test information about the likelihood that the chemical could cause cancers, birth defects, or mutations.

In the absence of data on the physical-chemical properties of chemicals used to assess environmental effects under the PMN review process, EPA relies on estimates of chemical properties and the use of computer models to determine whether the use of a new chemical may affect groundwater.[19]

Section 6. This section provides EPA with broad authority to address sources of groundwater contamination directly by regulating the use or disposal of a chemical substance or mixture.[20] To date, EPA has regulated four chemicals or groups of chemicals under Section 6: 1) fully halogenated chlorofluorocarbons, 2) waste materials containing tetrachlorodibenzo-p-dioxin (TCDD), 3) asbestos, and 4) polychlorinated biphenyls (PCBs).[21] Only the PCB regulations involve disposal provisions related to preventing groundwater contamination. However, one State in responding to OTA's State survey noted that the PCB disposal regulations are not being strictly enforced by EPA and that TSCA does not provide for the transfer of regulatory authority to the States. The TCDD requirements prohibit the disposal of wastes containing TCDD by a particular chemical company (which is under court order to undertake remedial actions at a hazardous waste site under RCRA); the company is required to store and monitor the wastes until a long-term solution is found.

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[17] Other sections of TSCA provide for: the compilation of an inventory of existing chemicals manufactured or processed in the United States and the recording and reporting of certain health and environmental data (Section 8); the development of test rules on health and environmental effects of existing chemicals (Section 4); the commencement of civil actions when chemical substances pose an imminent hazard (Section 7); and the authorization of State grants for establishment and operation of programs to prevent or eliminate unreasonable risks (Section 28).

[18] Section 5(d)(1).

[19] EPA's Office of Toxic Substances has undertaken two projects to support the premanufacture review process. One involves a computer program, CHEMEST, which estimates certain chemical properties on the basis of molecular structure information (Arthur D. Little, 1983). The program is capable of providing estimates of the following properties: solubility in water; the soil adsorption coefficient; bioaccumulation or the bioconcentration factor (in fish); the activity coefficient; the boiling point; the vapor pressure; the rate of volatilization from water; and Henry's Law Constant.

The second project involves the development of two models used to assess the behavior of a chemical in soil and groundwater. One model predicts movement through the unsaturated zone (Bonazountas, et al., 1981), and the other simulates the transport of contaminants through an aquifer (Yeh, 1981). Information compiled on 70 locations in the United States is the data base for these computer modeling efforts (Versar, 1983).

[20] Section 6 requires the Administrator of EPA to take one or more of the following actions if there is a reasonable basis to conclude that the manufacture, processing, distribution in commerce, use, or disposal of a chemical substance or mixture (or any combination of activities) presents or will present an unreasonable risk of injury to health or the environment:

1. prohibit or limit the amount of such substance or mixture which can be manufactured, processed, or distributed;
2. prohibit or limit the amount of such substance or mixture which can be manufactured, processed, or distributed for a particular use or a particular use in excess of a specified level;
3. require that such substance or mixture be accompanied by clear and adequate warnings and instructions with respect to its use, distribution in commerce, and/or disposal;
4. require manufacturers or processors of such substance or mixture to make and retain records of certain processes;
5. prohibit or otherwise regulate any manner or method of commercial use of such substance or mixture;
6. prohibit or otherwise regulate the manner or method of disposal of such substance or mixture provided that State (or other level of government) laws or requirements are not violated, and require notification of the appropriate level of government; and
7. direct manufacturers or processors of such substance or mixture to give notice of such unreasonable risk of injury and replace or repurchase such substance or mixture.

The factors which must be considered in promulgating a Section 6 rule include:

Federal Insecticide, Fungicide, and Rodenticide Act

The overall thrust of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which regulates pesticides in the United States, is to ensure that the use of a pesticide will not cause unreasonable adverse effects on the environment.[22] FIFRA defines an unreasonable adverse effect on the environment as "any unreasonable risk to man or the environment, taking into account the economic, social and environmental costs and benefits of the use of any pesticide." FIFRA contains two principal provisions relevant to the prevention of groundwater contamination: 1) Section 3 provides for the registration of all pesticides based on the submission of data specified by EPA and for the classification of pesticides for general or restricted use; and 2) Section 6 authorizes EPA to suspend and cancel the registrations of pesticides that cause unreasonable adverse effects on the environment.[23]

Section 3. Section 3 of FIFRA requires the registration of all pesticides. In addition to registering new pesticides, EPA is also mandated to review all existing registrations to ensure that they meet current requirements.[24] There are 40,000 pesticides (containing some 1,400 active ingredients in 578 generic categories) now registered by EPA.

For a pesticide to be registered, FIFRA requires determinations including that it will function as intended without unreasonable adverse effects on the environment, and when used in accordance with widespread and commonly recognized practice, it will not generally cause unreasonable adverse effects on the environment.[25]

EPA issued final regulations establishing basic registration requirements in July 1975.[26] The pesticide registration regulations enumerate three risk criteria for EPA use in determining whether a pesticide causes an unreasonable adverse effect: 1) acute toxicity in humans, other mammals, or birds, 2) chronic toxicity in humans, test animals, or endangered species, or population reductions in non-target organisms, and 3) lack of emergency treatment for ameliorating the toxic effects of a pesticide in people.[27] The regulations did not iden-

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A. the effects of such substance or mixture on health and the magnitude of the exposure of human beings to such substance or mixture;
B. the effects of such substance or mixture on the environment and the magnitude of the exposure on the environment to such substance or mixture;
C. the benefits of such substance or mixture for various uses and the availability of substitutes for such uses; and
D. the reasonably ascertainable economic consequences of the rule, after consideration of the effect on the national economy, small business, technological innovation, the environment, and public health (Section 6(c)(1)).

[21] See 40 CFR 762, 40 CFR 775, 40 CFR 763, and 40 CFR 761, respectively. Procedures for rulemaking under Section 6 are specified in 40 CFR 750. Congress explicitly directed EPA to promulgate disposal and labeling requirements for PCBs within 6 months of the effective date of TSCA and to phase out their use over a 2-year period; the PCB disposal requirements established by EPA with respect to monitoring, correction actions, and design and operation are discussed in chs. 6, 9, and 11, respectively.

[22] See Section 2(bb). Like TSCA, FIFRA does not explicitly include groundwater in the definition of environment.

[23] Other sections of FIFRA authorize EPA to: certify pesticide applicators to ensure that they are competent with respect to the use and handling of restricted pesticides (Section 4); establish procedures and regulations for the disposal or storage of packages and containers of pesticides or excess amounts of pesticides (Section 19); formulate a National Monitoring Plan (Section 20); and authorize certain State responsibilities (Sections 24 and 26).

[24] The 1972 amendments to FIFRA established the re-registration requirement. Subsequent amendments have attempted to streamline the re-registration process by authorizing EPA to develop generic standards for pesticide ingredients. These standards are used to review both new and existing registrations of individual products containing those ingredients. As of April 1984, EPA had issued 75 generic standards. Anticipating that generic standards are needed for 400-500 categories of pesticides, EPA is currently developing such standards at a rate of 25 per year (Auerbach, 1984).

[25] Section 3(c)(5).

[26] 40 CFR 162, Subpart A.

[27] 40 CFR 162.11(a)(3).

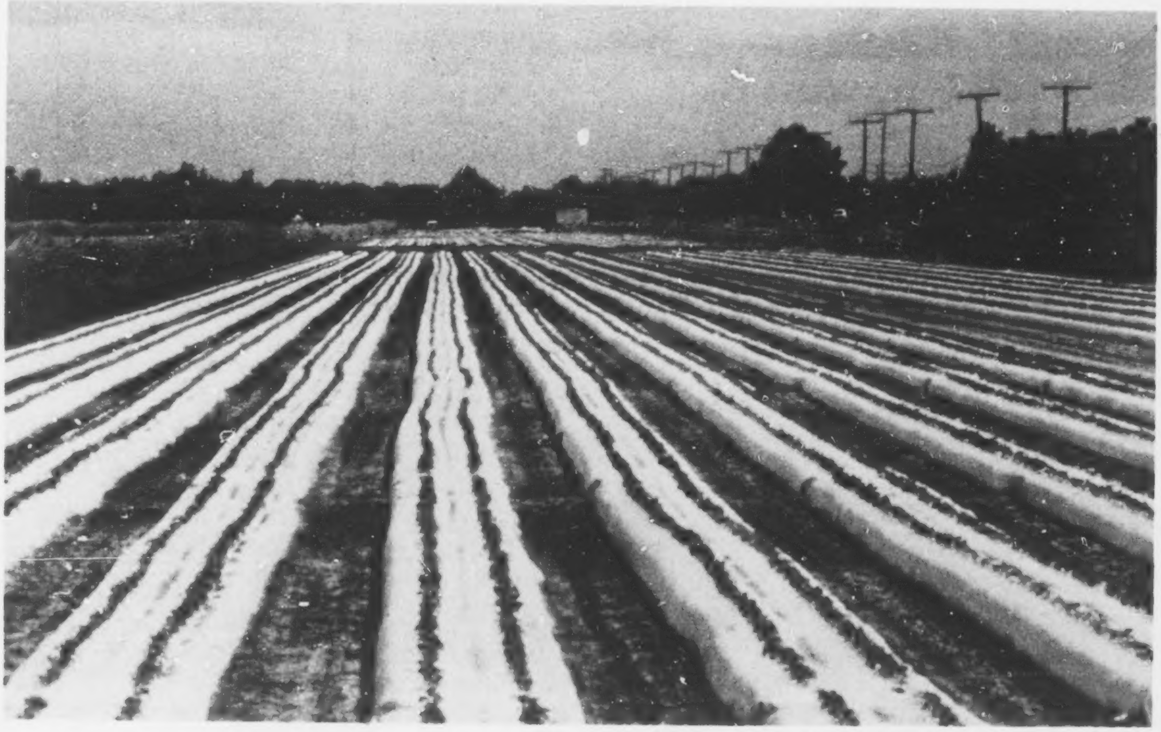

Photo credit: State of Florida Department of Environmental Regulation

Pesticides may be introduced into groundwater from non-point sources such as land application, as well as from point sources of hazardous wastes (e.g., landfills), non-hazardous wastes (e.g., residential disposal), and non-waste products (e.g., storage tanks).

tify the types of data needed to satisfy the statutory registration requirements. However, EPA developed guidelines between 1975 and 1981 describing such data requirements. In November 1982, EPA proposed regulations that reorganized the guidelines and listed the specific types of data and information needed to support a pesticide registration.[28]

Guidelines published by EPA as a companion document to the 1982 proposed regulations identify the following characteristics of a pesticide as being most pertinent to an evaluation of its potential to contaminate groundwater: leachability; adsorption/desorption characteristics; resistance to chemical, photochemical, and biological degradation; solubility in water; and volatility (EPA, 1982).[29] For the assessment of these characteristics, EPA's proposed regulations require the submission of data resulting from degradation, metabolism, mobility, dissipation, and accumulation studies.[30]

Section 3(d) of FIFRA requires EPA to classify pesticides (as part of the registration process) for general or restricted use. A pesticide is classified for restricted use:

> . . . if, the Administrator determines that the pesticide, when applied in accordance with its directions for use, warnings and cautions and for the uses for which it is registered, or for one or more of such uses, or in accordance with a widespread and commonly recognized practice, may generally cause, without additional regulatory restrictions, unreasonable adverse effects on the environment, including injury to the applicator. . . .[31]

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[28] 47 FR 53192, Nov. 24, 1982.

[29] This EPA document supports 40 CFR 158, Subdivision N, Proposed Data Requirements for the Registration of Pesticides, 47 CFR 53192.

[30] 40 CFR 158.130, 47 FR 53205. Environmental fate data requirements were issued as a public draft in 1978 and again in October 1980; see 47 FR 53194 and EPA, 1982.

[31] Section 3(d)(1)(C).

The statute provides that if a pesticide is classified for restricted use on the basis of *human health hazards* caused by acute dermal or inhalation toxicity, the pesticide can be applied only by a certified applicator.[32] If a pesticide is classified for restricted use because it may cause an unreasonable *adverse effect on the environment*, the Administrator of EPA must require that it be applied by a certified applicator *or* be subject to such other restrictions as may be provided by regulation.[33]

The regulations regarding restricted use classifications do not state the specific types of actions that could be included in the "other restrictions" category.[34] However, the legislative history of FIFRA indicates that other restrictions might include geographic controls over the use of a pesticide (Costello, 1983).[35] The regulations do specify that a pesticide product classified for restricted use must bear a label that contains the statements of the restricted use classification and directions for use;[36] these label restrictions could be used to prohibit the use of certain pesticides in specified areas (e.g., recharge areas) or to specify application procedures that prevent groundwater contamination (e.g., limiting the amounts or the rate of application) (Severn, et al., 1983).[37]

Section 6. This section of the act allows the EPA Administrator to suspend and cancel the registration or change the registration of a pesticide (e.g., from general to restricted use). A suspension order may be issued by EPA if it is determined necessary for preventing an imminent hazard during the time required for cancellation or change in classification proceedings.[38]

A pesticide registration can be canceled or its classification changed if the pesticide causes unreasonable adverse effects on the environment when used in accordance with widespread and commonly recognized practice or if its labeling or other material required for submission to EPA does not appear to comply with the provisions of FIFRA.[39] Although actions taken under Section 6 are based on a finding of unreasonable risk to humans and the environment (i.e., a determination that acute toxicity or chronic toxicity exceed criteria or that there is no emergency treatment), information regarding the potential of a pesticide to leach through the soil into groundwater can be factored into EPA's assessment of exposure to pesticides that do meet the risk criteria.[40]

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[32] Section 3(d)(l)(C)(i). A certified applicator must be competent in the use and handling of pesticides. EPA regulations identify competency standards. They include a demonstration of practical knowledge with respect to the environmental effects of the use or misuse of pesticides. See 40 CFR 171.

[33] Section 3(d)(1)(C)(ii).

[34] See 40 CFR 162.30. The regulations indicate, however, that the risk criteria specified by 40 CFR 162.11(a)(3) are to be used in determining whether the use of a pesticide should be restricted.

[35] The report of the Senate Committee on Agriculture and Forestry explained that although a third type of classification (permit only) was rejected, EPA was not constrained "from regulating the quantity to be applied for a given use for a particular application to a particular crop in a given area at a given time, from limiting the number of applications, or from prohibiting the use thereof. . . . " (U.S. Senate, 1972).

[36] 40 CFR 162.30(q).

[37] Label restrictions have been imposed for the use of aldicarb on Long Island, NY, in response to a request from the manufacturer.

[38] Section 6(c)(1). An imminent hazard is defined in FIFRA, in Section 2(1), as "a situation which exists when the continued use of a pesticide during the time required for a cancellation proceeding would be likely to result in unreasonable adverse effects on the environment or will involve unreasonable hazard to the survival of a species declared endangered by the Secretary of the Interior under Public Law 91-135."

[39] Section 6(b)(1). Pursuant to Section 6(a)(1) of FIFRA, a pesticide registration shall also be canceled at the end of any 5-year period which begins on the date of its registration unless a continuation is requested.

[40] See, for example, 48 FR 46234, Oct. 11, 1983 (46238). It is also important to underscore the fact that a finding of unreasonable risk under FIFRA involves a process that weighs health risks against the benefits of continued use of the pesticide.

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Chapter 12

Overview of the States and Prevention

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Overview of the States and Prevention

CHAPTER OVERVIEW

In this chapter, State responses to survey questions about their activities to prevent groundwater contamination are briefly described.[1] (See the section *OTA State Survey* in ch. 4 for guidance in interpreting survey results.) Approaches that States use for prevention are highlighted along with programs for sources, aquifer protection, and impact reduction.

In summary, the States are using a variety of approaches to prevent groundwater contamination. They give priority to and are developing and implementing programs for prevention of contamination from particular sources, especially waste-related point sources.

States' problems with prevention and desires for Federal assistance are discussed in chapter 4. The chapter describes the States' problems with prevention as mostly institutional. The States noted a lack of prevention programs, deficiencies in some types of programs, and a lack of resources to implement existing institutional mechanisms. The technical adequacy of prevention mechanisms is also a concern. The States want Federal assistance for prevention mostly in the form of funding and research and development on control techniques for additional sources. They also want the Federal Government to assist information exchange among the States and to improve Federal prevention programs that they perceive as unsuccessful.

STATE PREVENTION APPROACHES

The States use a variety of approaches to prevent contamination—directed at sources, aquifer protection, and impact reduction. These approaches, which vary among the States, consist of components including: siting requirements; design and operating requirements (e.g., discharge requirements, Best Management Practices, construction standards, and closure standards); land use controls; and deed restrictions.

Programs have already been implemented in many States. In others, programs are being developed. Legislation is required in a small number of States (fewer than 10) to authorize programs that they are working to develop.

Different components of State prevention programs may be mandatory or voluntary. For example, mandatory permit requirements may apply to facility siting and/or design and operation; through technical assistance and public education activities, a State may encourage voluntary use of Best Management Practices to minimize the potential for contamination from particular activities and facilities.

Groundwater classification systems, general policies about the degradation of groundwater, and/or the protection of public health and the environment guide implementation of prevention programs in some States. Classification systems have both advantages and disadvantages when used for this purpose (as described by Miller, 1984). Advantages relate primarily to establishment of a formal mechanism for determining where and to what extent water quality protection measures are applied. Disadvantages relate primarily to technical difficulties in establishing classification boundaries (e.g., insufficient data) and policy conflicts in defining water quality objectives for various classifications (e.g.,

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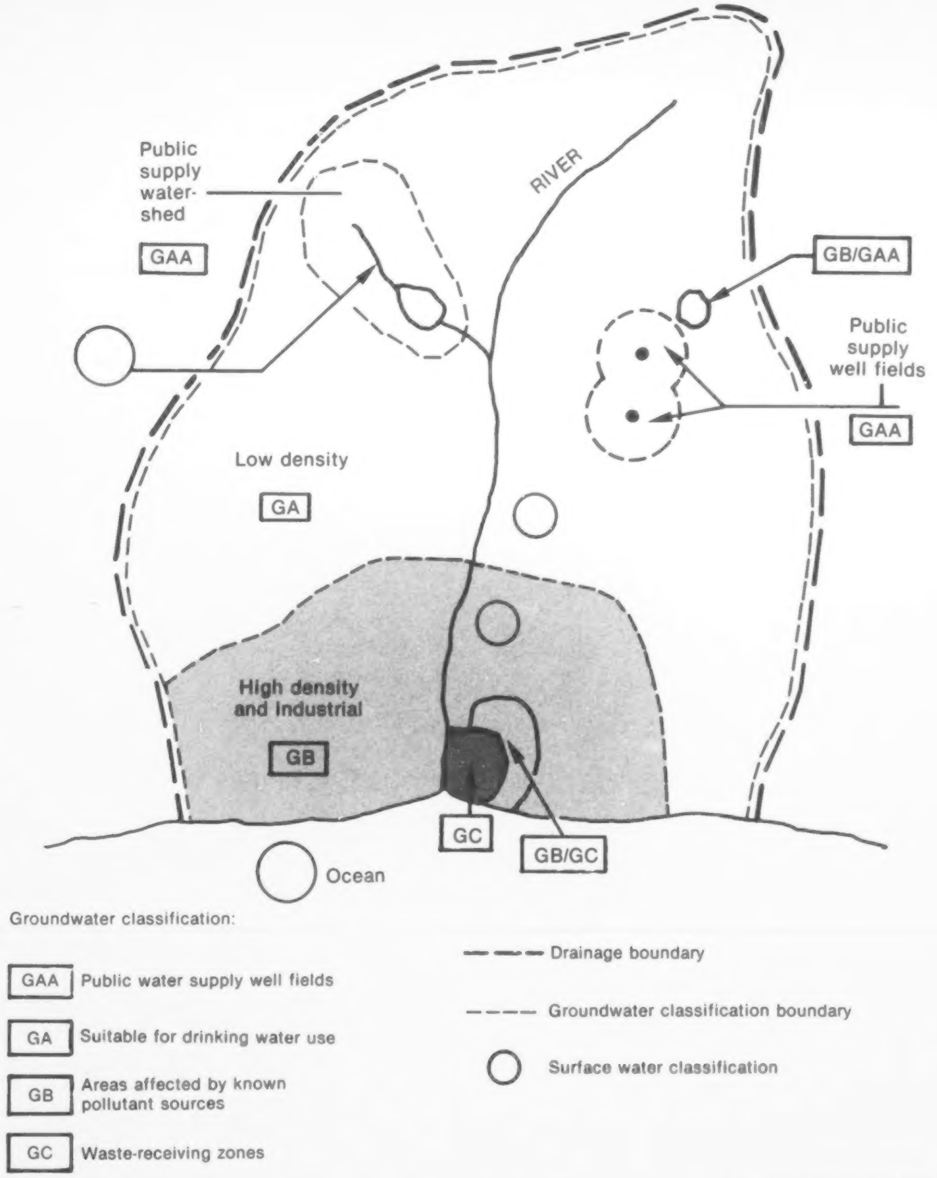
[1] Given the OTA study focus on already contaminated groundwater, the OTA survey did not question the States on their use, preferences, and problems with specific techniques for prevention. For more detailed accounts of selected State programs see Henderson, et al., 1984.


Public supply water-shed
GAA
RIVER
GB/GAA
Public supply well fields
GAA
Low density
GA
High density and industrial
GB
GC
GB/GC
Ocean
Groundwater classification:
GAA Public water supply well fields
GA Suitable for drinking water use
GB Areas affected by known pollutant sources
GC Waste-receiving zones
Drainage boundary
Groundwater classification boundary
Surface water classification

Credit: Geraghty & Miller, 1983

Groundwater classification schemes are used to facilitate decisions about groundwater quality protection in some States. The example shown illustrates the groundwater classification system applied by the State of Connecticut.

acceptability of allowing a resource to be degraded in certain areas).[2] Even if classification systems are not used as a formal basis for decisionmaking about siting or the design and operation of facilities, the aquifer information that is associated with these classifications usually contributes to prevention decisions as well as decisions on priorities for detection and correction. Twenty-three States classify groundwater on the basis of various characteristics useful for making prevention decisions. For example, classifications are based on: the natural quality differences in aquifers which affect water use (e.g., total dissolved solids); characteristics that may make aquifers vulnerable to contamination (e.g., water table v. confined aquifers); characteristics that affect the development of water supplies (e.g., high v. low yield); and variations in population, average use rate, contamination problems, and availability of alternative groundwater resources.

Source Programs

Prevention programs that the States have either implemented or are developing are related primarily to sources. Ten States explicitly commented on the limited coverage of their prevention activities—that programs do not address all recognized sources of potential contamination. For example, one State noted that many of its programs are applicable only to landfills, wastewater lagoons, and land applica-

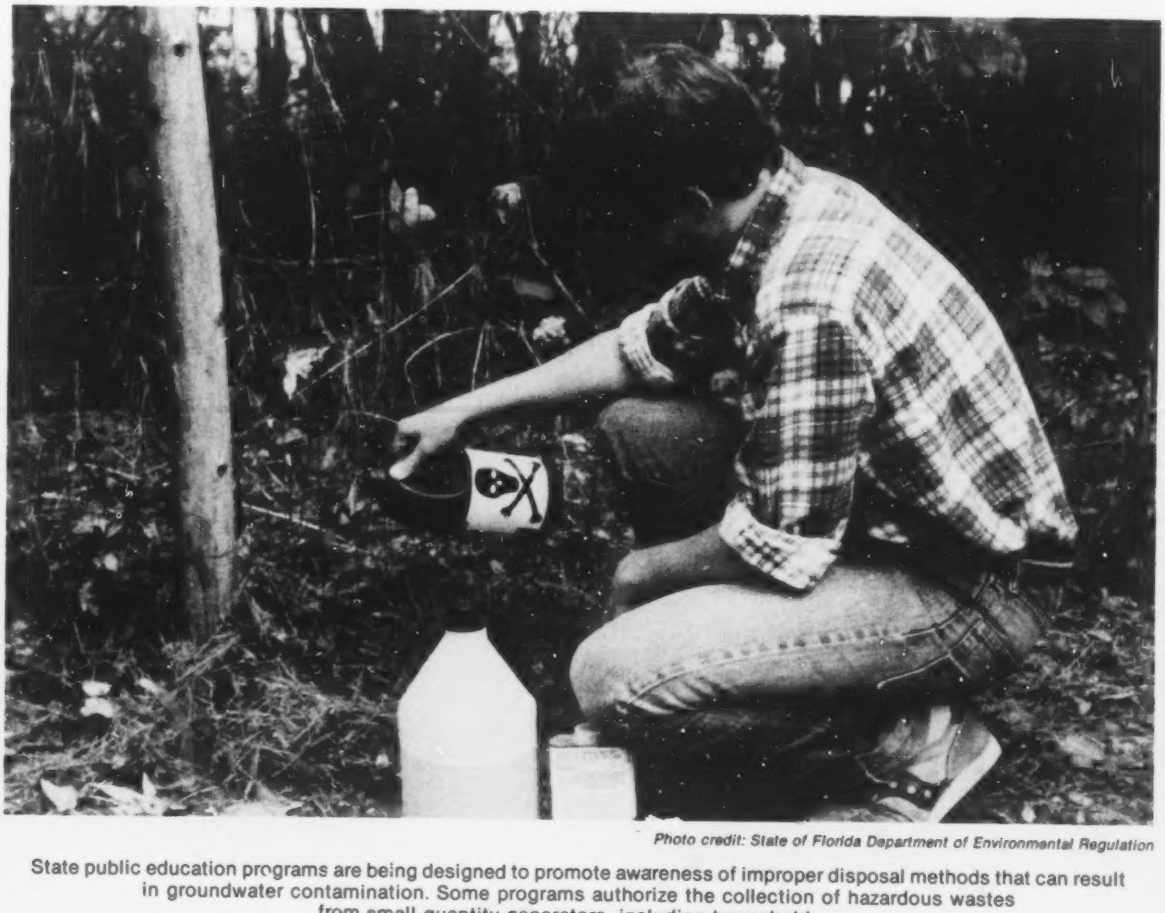


Photo credit: State of Florida Department of Environmental Regulation

State public education programs are being designed to promote awareness of improper disposal methods that can result in groundwater contamination. Some programs authorize the collection of hazardous wastes from small quantity generators, including households.

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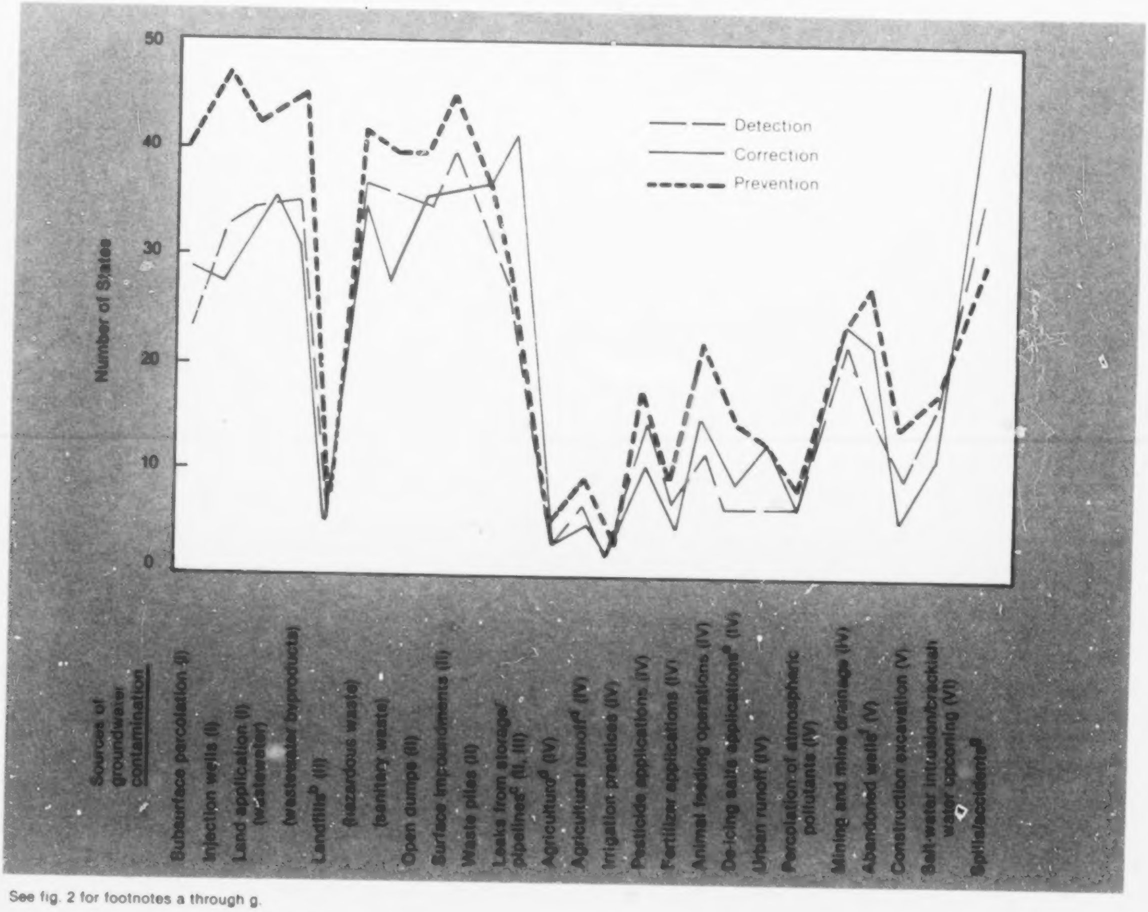
[2] For a detailed discussion of advantages and disadvantages of groundwater classification systems and a description of some State programs, see Magnuson, 1981. Additional State classification programs are described in Pye, et al., 1983 and API, 1983.

tion of sewage sludge, and are not applicable to agricultural activities. In general, waste-related point sources are addressed in more States than non-waste and non-point sources.

As shown in figure 6, more States have programs for prevention of contamination from various sources —and give priority to these programs—than for detection or correction of contamination. Also, more States have prevention programs for and give priority to sources in OTA Categories I (e.g., injection wells) and II (e.g., surface impoundments) than in Categories III, IV, V, and VI. Not all facilities and/or activities for each of these source types are covered in State prevention programs. For example, in one State, well construction standards apply only to drinking water wells; in another, such standards apply to all wells in artesian (confined) aquifers; and in a third State, although standards apply to all wells, they are not strictly applied to private wells or to agricultural wells.

Permit programs for design and operation of different sources may be oriented to the overall performance of a facility or related to certain technology requirements. For example, facilities that discharge substances to groundwater may have to satisfy groundwater quality standards. Technology

Figure 6.—OTA State Survey Responses: Number of States With Programs to Prevent Groundwater Contamination From Selected Sources



See fig. 2 for footnotes a through g.

SOURCE: Office of Technology Assessment.

Mobil
FIBERGLAS

Photo credit: U.S. Environmental Protection Agency

Voluntary replacement of underground gasoline storage tanks is one technique that many States rely on to prevent groundwater contamination.

requirements may include, for example, the use of liners and leachate collection systems for landfills and septic tanks of specified sizes.

Aquifer Protection

A few States have programs that address the protection of aquifers and/or recharge areas. For example, in some States where sole source aquifers have been designated, State or local restrictions have been placed on certain activities (see ch. 11). One State provides funds for municipalities to purchase land for aquifer protection.

Impact Reduction

Although most State activities appear to be directed at preventing (or minimizing the potential for) groundwater contamination, some States have programs to prevent adverse impacts associated with potential contamination. For example, in one State solid waste facilities must be recorded on property deeds. This measure is intended to avoid the unknowing purchase of former landfills.

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